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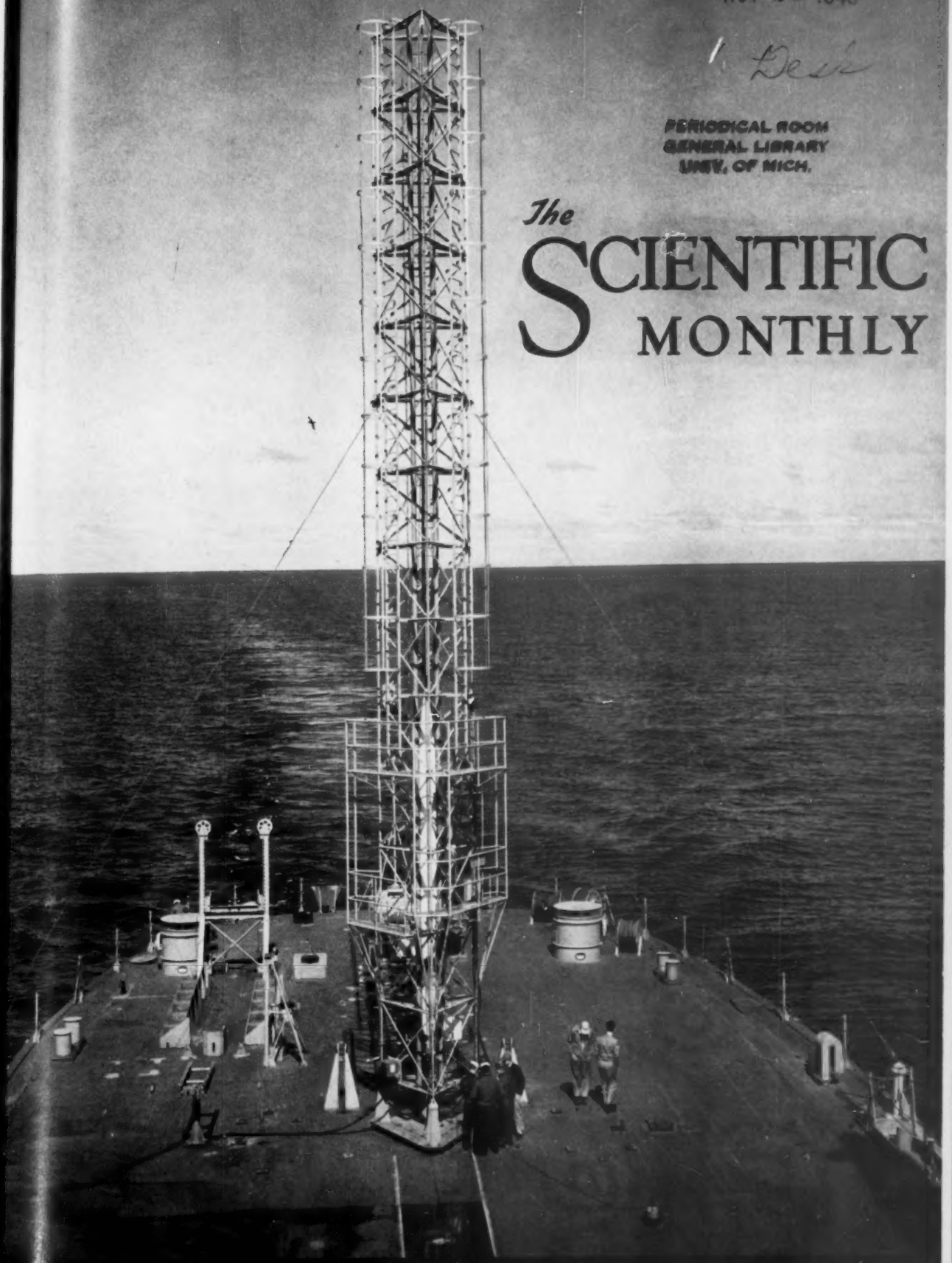

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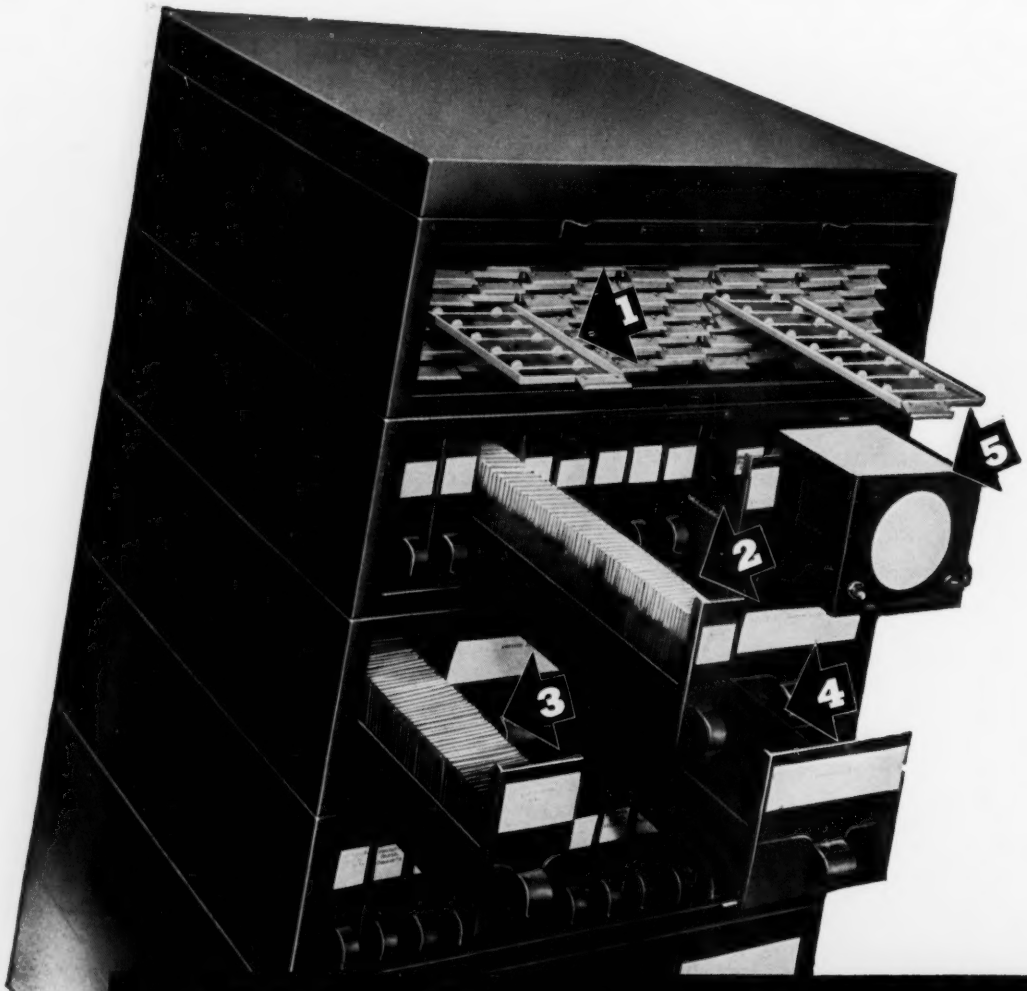

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ISOTOPES—THEIR DISTRIBUTION AND USE

PAUL C. AEBERSOLD

From 1938 to 1942 Dr. Aebersold (Ph.D., California, 1938), under the direction of Dr. Ernest O. Lawrence, inventor of the cyclotron, was associated with physics and biophysics research at the Radiation Laboratory, University of California. During the war he worked on various phases of the atomic energy project in Berkeley, California, Oak Ridge, Tennessee, and Los Alamos, New Mexico. In 1946 he became chief of the Isotopes Branch of the Manhattan District and is now chief of the Isotopes Division of the Atomic Energy Commission, which supplies isotopes to hundreds of research institutions, universities, and hospitals all over the world.

IN THE first three years of the United States program of isotope distribution, from August 2, 1946, to June 30, 1949, more than 7,000 shipments of radioactive isotopes and 731 shipments of concentrated stable isotopes were made to government, private, and industrial laboratories for use in peacetime research. All the shipments were made from facilities now controlled by the U. S. Atomic Energy Commission. The isotopes were distributed for use in all the major fields of scientific investigation, as well as for applications in medicine, agriculture, and industry. The radioactive isotopes went to 549 departments in 305 institutions located in 39 states, the District of Columbia, and Hawaii, and to 150 institutions in 21 foreign countries. The concentrated stable isotopes went to 209 departments in 144 institutions within the continental United States.

Radioisotopes were distributed for use as tracer atoms and as sources of ionizing radiations. Tracer atoms are used in all fields of basic and applied study in which knowledge is desired on the movement, transformation, and chemical behavior of atoms and molecules. As sources of ionizing radiation, radioisotopes are used in medicine for detecting and treating certain diseases, and in industry for radiographic testing and process-control applications. The stable isotopes were distributed for use as tracer atoms and as objects of nuclear study. As tracer atoms the stable isotopes were also widely used in all major fields, and as objects of investigation per se they were mainly used by nuclear physicists and chemists.

What does a program, already grown to such magnitude and still growing rapidly, mean to the over-all advancement of modern science? Is government control of isotope distribution a handicap to their maximum usefulness? What precautionary steps have been taken with respect to the health-hazard aspects of radioisotope distribution? What are the security risks, if any, in making distribution to laboratories in foreign countries of these materials, many of which are direct by-products of atomic energy? Is the use of isotopes a passing "fad"? Presentation of this summary on the status of isotope distribution and utilization is intended to help provide an answer to these general questions, as well as a better over-all understanding of the program.

Development of distribution program. The use of naturally occurring radioisotopes, such as radiolead and radium, as radioactive indicators, or "tracer" atoms, dates back to the late 1910s. It was not until the middle 1930s, however, that the artificial induction of radioactivity permitted radioisotopes of the more common elements to come into usage as tracer atoms. Through the

medium of the cyclotron it became possible to produce radioactive species, or radioisotopes, of all the elements. With a few exceptions, one or more radioisotopes, having radiation characteristics suitable for tracer or other applications, could be produced of each element. There was, however, one great drawback to the widespread use of cyclotron-produced isotopes—the expense and small-scale capacity of production. Although radioisotopes were used appreciably in laboratory-scale research investigations and in certain applications for medical treatment, this work was chiefly limited to a dozen or so institutions possessing cyclotrons.

Before World War II those scientists who had used radioisotopes had formed a keen appreciation of their usefulness. They had found, for instance, that radioisotopes could be used to label uniquely a specific batch of atoms, which could then be traced through a labyrinth of chemical or physical reactions. The labeled atoms could be traced independently even in the presence of other atoms or molecules of the same substance, and in spite of multiple reactions of numerous other kinds of atoms and molecules. It was also found that radioactivity detection instruments could reveal the presence of extremely minute quantities of radioelements—quantities millions and sometimes even billions of times smaller than those detectable by chemical means.

Thus, even before the war, science had in radioisotopes a research tool with the twofold power of extremely high sensitivity and unique specificity. It was a tool greatly in demand but small in availability.

During the war many of the scientists who were familiar with cyclotrons and the handling of radioactivity became associated with the development of the atomic energy project. They soon realized that the uranium chain reactor would be an excellent unit for large-scale production of a wide variety of useful radioisotopes. At the conclusion of the war these scientists, realizing the potential value of radioisotopes to peacetime research, proposed that reactor-produced radioisotopes be made generally available for scientific investigation. Working jointly with the Manhattan District, Corps of Engineers, U. S. Army, the original operators of the atomic energy project, they formulated a program based on this proposal. The present isotope distribution program is a direct outgrowth of that early planning. Although the spadework connected with establishing the program was mainly completed at that time, most of the responsibility for its administration has come under the jurisdiction of the Atomic Energy Commission.

Increased availablity of isotopes. To appreciate the capacity of a nuclear reactor for radioisotope production, one has only to compare it with a cyclotron. Production of the most widely useful isotopes in both units is based primarily on inducing radioactivity into stable target elements. In the reactor the target elements are bombarded only with the neutrons of the chain reaction, whereas in a cyclotron much more versatility is possible in the type and energy of the bombarding particles. In the nuclear reactor there is also a vast source of radioisotopes in the radioactive fragments resulting from fissioning, or splitting, of the uranium employed in the chain reaction. These are the so-called fission products.

Because of the extremely high density of neutrons (approximately 5×10^{11} neutrons/cm^2/sec.) available in the reactor for bombarding target elements, and because of the over-all size of the reactor, it is possible to produce thousands to many millions of times as much radioactivity as in a cyclotron. Also, because of the reactor size, it is possible simultaneously to induce radioactivity in hundreds of different target materials. Although there are a number of very useful radioisotopes that cannot be produced by neutron bombardment, thus requiring cyclotron production, most of the widely useful isotopes can be produced in a reactor.

With reactor production facilities, distribution would no longer have to be limited to a relatively small number of investigators, and research workers would not have to limit their investigations to those experiments requiring minimum quantities of tracer materials. Production would be sufficient for investigators to trace not only elements and simple inorganic compounds but also complex organic compounds and biological materials, even though the synthesis of such labeled materials would be inefficient in the use of active material.

The development of stable isotope separation and utilization has followed a similar pattern. Prior to the war, stable isotope separation was accomplished by electrolysis, exchange reactions, and fractional distillation on a very small scale. Deuterium, or hydrogen 2, carbon 13, and nitrogen 15 were the only stable isotopes, which were concentrated in quantities sufficient for significant tracer use. Stable isotopes of many elements can now be concentrated by large-scale electromagnetic separators similar to those used during the war for the mass-scale separation of fissionable uranium 235 from

nonfissionable uranium 238. Approximately 130 different concentrated stable isotopes are now available to investigators in this country.

Stable isotopes are generally not as applicable as radioactive isotopes for tracer investigations because they can only be identified on the basis of differences in weight. This determination requires costly instrumentation and is much less sensitive than the methods used in radioactivity measurements. Stable isotopes have, however, proved very valuable as tracers in investigations where it is not permissible to introduce radioactivity, or where great sensitivity is not required. They are, of course, also invaluable for fundamental nuclear studies requiring isolated nuclear species.

Criteria of production and distribution. Before the isotopes distribution program could be initiated, certain criteria for both production and distribution had to be established. This was especially true for radioisotopes because of the variety of health-safety problems involved. In distributing stable isotopes, on the other hand, the principal problems were concerned with limited availability and cost. Answers had to be found for such questions as: What radioisotopes should be produced and in what quantity? In what chemical form should the isotopes be made available? To whom should isotopic materials be made available? What portion of the production costs should be borne by the prospective user? What, if any, limitations should be placed on the applicant?

A number of such questions were automatically answered by the Atomic Energy Act of 1946. Answers to others have been tentatively determined by the Atomic Energy Commission and its advisory groups in the best interest of the distributor and the isotope user. In some instances, such as in price scheduling and in procurement procedures, it has been necessary to make adjustments from time to time to meet changes in availability and demand.

To assist in the formulation of policies under which isotopes would be distributed, the Commission appointed a Committee on Isotope Distribution. This Committee, composed of twelve members, scientists and physicians who have had considerable experience in the handling and use of radioactivity, is subdivided into a Subcommittee on General Applications and a Subcommittee on Human Applications. Besides making recommendations to the Commission on basic policies governing allocation and distribution, the Subcommittee on Human Applications reviews all requests proposing to use radioisotopes in human beings, and the Subcommittee on General Applications reviews requests proposing to use large quantities of activity in experimentation outside the laboratory.

Because radioactive materials are potentially hazardous to health, it is necessary that the prospective user have adequate facilities, proper safety equipment, and specialized scientific background to insure their safe handling and use. It is also necessary to know what use will be made of the radioisotopes. These requirements are set forth in the Atomic Energy Act. The Atomic Energy Commission and its advisers have given these directives as liberal interpretations as was deemed feasible. The Commission has, for instance, adopted the philosophy that it is better to expend effort and money on educating isotope users in proper techniques than on attempting to police the health-safety aspects of isotope work. Although the policies may lean toward the conservative side, they have paid dividends in health safety. In more than three years of isotope distribution no case has been noted of injury to an individual using or handling radioisotopes.

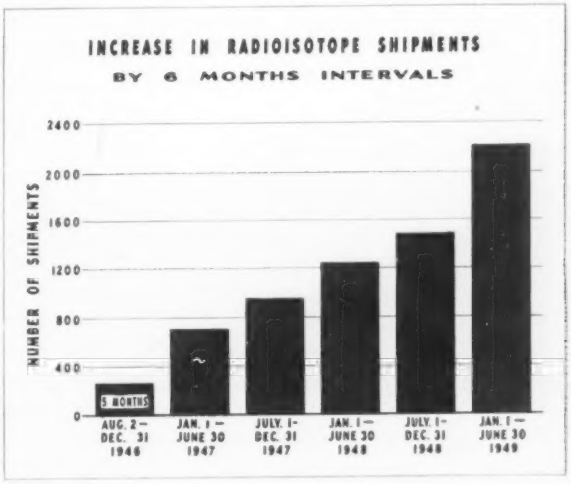

FIGURE 1.

The isotope user is allowed to obtain safety equipment of his own choice and to design laboratory facilities that best suit his own needs. The requirement that the applicant indicate his proposed use of the material is primarily a safety measure. He is only required to show that proper use of the material will be made in a manner that is both feasible and safe. This assures maximum safety to both the investigator and all others likely to be exposed to the radiation. Disclosures of usage which the applicant desires to keep confidential are closely confined within the Commission. It is required, however, in the interests of accelerating

the peacetime applications of atomic energy, that the user agree to publish the results of his use of isotopes within a reasonable time. The user is nevertheless at liberty to obtain patent rights in the usual manner to inventions resulting from his use of isotopes.

Production improvements. When the program first started, requests for isotopic materials warranted the immediate production of a wide variety of radioisotopes. The task of preparing approximately one hundred different varieties of radioisotopes made it necessary to limit their availability to the simplest and most generally adaptable chemical forms. But by placing the emphasis here, it was possible to make these "basic products" available cheaply and on a large scale. At first, production was limited because of the many new problems to be overcome. During the war the reactor laboratories were chiefly concerned with problems related to plutonium production. Little work had been done on developing production processes for those radioisotopes that would be most in demand for research, especially for use in biology and medicine. Initially, therefore, distribution of certain items had to be governed by a priority system outlined in the Atomic Energy Act. This provides that first priority be given to uses in fundamental research and medical therapy. In the past two years, however, the chief center of radioisotope production, the Oak Ridge National Laboratory, which is operated for the Commission by the Carbide and Carbon Chemicals Corporation, has markedly increased total production. Priority distribution is no longer necessary.

Improvements in quality production have also taken place as the program has grown. Considerable improvement has been made in the chemical processing procedures for separating radioisotopes which have been prepared by transmutation from the original target material. In this particular type of nuclear reaction the stable isotope of one element is converted into a radioactive form of another element, and the radioactive atoms may then be chemically separated from the stable atoms. Investigators receiving shipments of such separated radioisotopes can now be reasonably assured that the material will meet specifications of greater than 99 percent radiochemical purity. Although the production operators do not guarantee chemical and radiochemical purity, every effort is made to produce as high-quality material as possible. A continued effort has also been made to improve chemical specifications and the reliability of chemical analyses.

In at least one instance, quality improvement has been effected by entirely changing the method of production. Only within the past year has radioactive iodine 131 been extracted routinely as one of the products of uranium fission. Prior to that time this isotope was prepared by subjecting tellurium to neutron bombardment. The new production method not only gives better yields and permits the preparation of much greater quantities, but also guarantees higher quality. The chemical impurities in the stable tellurium are no longer a source of chemical contamination of the end product. More recently, the method of producing radioactive carbon 14 has been slightly altered. Although preparation is still based on the transmutation of stable nitrogen, the target material has been changed from calcium nitrate to beryllium nitride. This particular change has been made primarily in an effort to increase efficiency of production; the higher concentration of nitrogen in the nitride permits a better yield and a higher-activity product.

Closely associated with quality improvements are the advances that have been made in increasing the amount of radioactivity in the final product. Improvements in health-safety features of the production facilities now make it possible to prepare, handle, and ship much larger quantities of activity in a single radioisotope shipment. This is an important feature to investigators requiring larger quantities of activity either for large-scale tracer experiments or for high-intensity radiation sources.

Even more important than increased total activity is the recently announced availability of materials with increased specific activities, that is, with greater activity per unit weight of the element. Any radioisotope having a half life greater than sixty days can be appreciably increased in specific activity through extended time of irradiation in the nuclear reactor. Twenty radioisotopes with increased specific activities are now available. These include radioactive tantalum, whose specific activity has been increased from 105 millicuries to 1,000–3,000 millicuries per gram of tantalum; radioactive calcium 45, increased from 0.3 millicurie to 5–10 millicuries per gram; and radioactive cobalt 60, increased from 30 millicuries to 2,000–3,000 millicuries per gram. For radiocobalt, which has been suggested as a substitute for radium in certain applications in medical therapy and industrial radiography, the new material has a gamma ray output per unit weight approximately three times that of radium.

Continued improvements in the availability of the basic isotopic materials can be expected as a

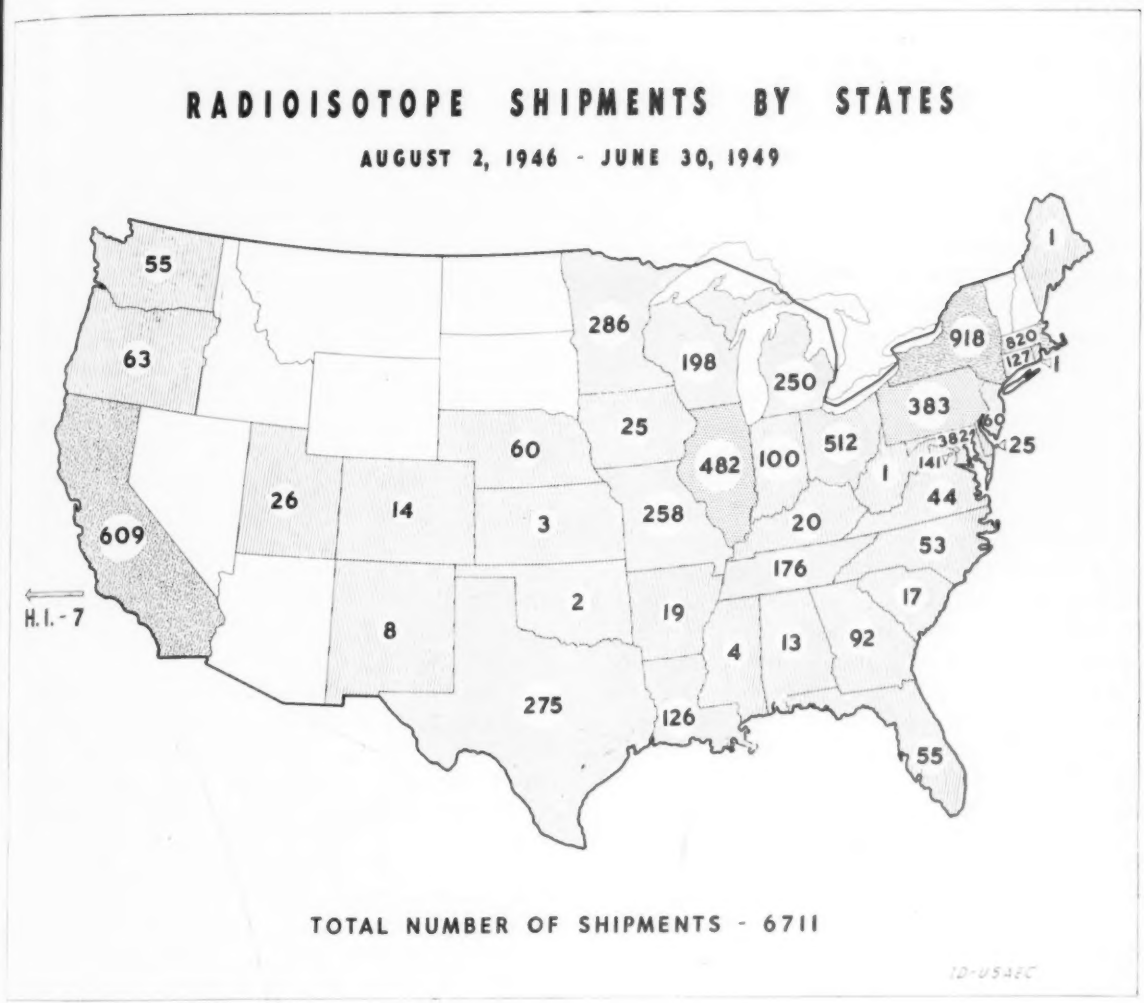

FIGURE 2.

result of recently improved facilities. Until quite recently almost all the radioisotopes made available through the distribution program had to be prepared and processed in temporary facilities originally built as a pilot-plant for plutonium production units at Hanford, Washington. The Commission has just completed, at the Oak Ridge National Laboratory, a new building for chemical processing of radioisotopes at a cost of almost $2,000,000. With these new facilities it is expected that much improvement will be made in production, processing, and shipping methods.

Improvements have likewise been made in the availability of concentrated stable isotopes as the distribution program has expanded. During the past year helium 3, boron 10 in elemental form, boron 11 in compound form, and 21 electromagnetically concentrated isotopes of sulfur, barium, cerium, tungsten, and mercury have been added to the list of more than 110 stable isotopes formerly available. Workers associated with the electromagnetic separation program will continue to build up a reserve, or "bank," of a wide variety of concentrated stable isotopes from which samples may be withdrawn and loaned as required for research purposes.

Cyclotron-produced isotopes. To extend further the availability of useful isotopes the Commission announced in June of this year that it would also make available certain long-lived radiomaterials which cannot be produced in a nuclear reactor but must be made in a cyclotron. To assist in this phase of the program, arrangements have been made with cyclotron laboratories of Massachusetts Institute of Technology, the University of Pittsburgh, the University of California, and Washington University. Target materials will be bombarded at these locations and then forwarded to

the Oak Ridge National Laboratory for chemical extraction and distribution of the desired isotope to the users.

The cyclotron is the only source of at least 10 very useful radioisotopes. These include such important species as beryllium 7, sodium 22, iron 59 free of iron 55, iron 55 free of iron 59, and iodine 125. It is also the only source of very high specific activity radioisotopes of over 15 elements, including beryllium, fluorine, manganese, iron, nickel, and zinc. It is believed that making these materials available to isotope users at a reduced cost through a central distributing agent will result in extending or supplementing many important studies now under way with reactor-produced isotopes. For example, studies with short-lived sodium 24 (14.8-hour half life) on body fluid volumes and ion transport across blood vessel walls can be greatly extended with long-lived sodium 22 (3-year half life). Conversely, short-lived iron 59 (46.3 days) free of long-lived iron 55 (4 years) can be used more safely in clinical studies.

Isotope-labeled compounds. At the start of the distribution program, as pointed out earlier, it was decided to make available as wide a variety as possible of radioisotopes in simple inorganic chemical forms. To a large extent this procedure has been continued as the program has grown. For certain types of utilization these simple basic forms are immediately applicable with little or no further chemical processing. For example, radioiodine for studying and treating various thyroid gland disorders is usually administered as an aqueous solution of sodium iodide, and radiophosphorus for treating polycythemia vera is administered as an aqueous solution of phosphoric acid. In both instances, these are the chemical forms in which the isotopes are shipped from Oak Ridge. The processing necessary for administration is usually limited to sterilizing, aliquoting, and buffering the radioactive solution.

But for most research uses of radioisotopes, the basic forms cannot be directly used. A modified form, or even an especially synthesized compound containing the isotope, is required. To use a tracer isotope such as radiosulfur, for instance, in studying the metabolic fate of a sulfur-containing amino acid, it is first necessary to incorporate the radioisotope in a specified way into the compound to be followed. The isotope-labeled compounds may be prepared either by chemical or biological synthesis. Not only are such compounds essential for many research problems, but they have proved useful in certain medical applications, such as the use of radioiodine-labeled diiodofluorescein for locating brain tumors.

Preparation of isotope-labeled compounds is an activity which has been largely left to the resources of individual investigators and private enterprise. At present three private laboratories—Tracerlab, Inc., Boston, Abbott Laboratories, Chicago, and Texas Research Foundation, Renner, Texas—are preparing such compounds for distribution. Over 275 shipments of approximately 60 different compounds have been made from these laboratories to date, and the rate of such secondary distribution is rapidly approaching 50 shipments per month. These are in addition to the limited number of compounds prepared in Commission laboratories and obtainable directly from the Commission.

The need for labeled compounds, however, still outweighs their availability—not so much in quantity as in variety of compounds. Synthesis procedures are often difficult, time-consuming, and expensive. This factor limits availability and makes the cost excessively high. It is a handicap to both the distributor and the potential user and, also, often prohibits the preparation of a potentially important labeled compound.

Synthesis of labeled compounds. To make a greater variety of isotope-labeled compounds available, the Commission has arranged to assist financially the development work necessary for synthesis of selected isotope-labeled compounds. Contracts have recently been made with six private laboratories equipped with the necessary special facilities and personnel to participate in this program. Compounds scheduled for synthesis include amino acids, such as methionine and glutamic acid; organic acids and derivatives, such as fumaric acid and phthalic anhydride; hormones, such as testosterone and progesterone; important dyes, such as Nile blue and fluorescein; and miscellaneous compounds, such as vitamins, nitrogen mustard, and penicillin derivatives.

In recent months the preparation of isotope-labeled compounds by biological synthesis has aroused much interest among isotope users. More than 50 different varieties of such compounds have been extracted from plant and animal products after their synthesis from simple chemical forms by metabolic processes. These compounds, however, have been mostly prepared in small quantities as by-products of individual research investigations and are therefore not available for distribution and wide-scale use. With a view to producing such biologically synthesized compounds in quantities sufficient for more extensive use, Oak Ridge and Argonne National Laboratories have initiated isotope "farm" programs. A "farm" in this case is a laboratory especially equipped to handle the administration of radioisotopes to ani-

mals and plants and to extract the labeled materials. Compounds scheduled for synthesis under this program include such materials as glucose, fructose, ascorbic acid, nicotine, opium, and morphine.

Results of use. Indication of the wide usefulness of isotopes is evidenced by the rapid expansion in isotope distribution. Figure 1, for example, shows that the number of isotope shipments made during the first six months of this year was nearly double that for the same period last year and more than triple the 1947 figure. An illustration of overall distribution within the United States is given in Figure 2. Further evidence and a more objective criterion of the value of isotopes are to be found in the nearly 1,900 publications that have already resulted from Commission-produced isotopes. These publications are listed in the report *Isotopes—A Three Year Summary of United States Distribution,* recently released by the Atomic Energy Commission.* Further illustrations of the many ways in which isotopes have been used are found in the *Fourth* and *Sixth Semiannual Reports of the Atomic Energy Commission* to Congress.* The *Fourth Report,* issued in July 1948, was devoted almost entirely to isotope utilization in peacetime research programs outside Commission laboratories. One of its appendices consists of progress reports from individual research men, in which they outline typical experimental investigations and findings. The *Sixth Report,* issued in July 1949, contains many examples of isotope utilization in biology and medicine.

In 1948 a report on the utilization of isotopes distributed by the Commission could be made only on the basis of individual progress reports. Now that there has been time for many of the investigations to be completed, it is possible to cover the field with a bibliography of published papers.

It would not be possible here to discuss in detail the hundreds of uses of isotopes. A summary of isotope utilization amounts to a representative cross section of all the research and investigation in the wide variety of fields in which isotopes are used. In view of the diverse interests of the readers of this journal, it seems desirable to present at least a brief summary of some of the major uses of isotopes.

Use in biology and medicine. In biology isotopes have been used to label and study a large number of body constituents and related substances. Materials which have been labeled and traced through complex body processes include phospholipids, sugars, proteins, nucleic acids, vitamins, hormones, antibodies, amino acids, drugs, dyes, organic acids, blood cells, and others. Isotopes have been used to develop an entirely new technique for studying metabolism and the synthesis, transport, utilization, and breakdown of various body compounds.

To date only a limited number of applications have been found for radioisotopes in medical diagnosis and therapy. Unfortunately, publicity in regard to such applications has usually surpassed actual achievements, especially in the diagnosis and treatment of cancer. Certain diagnostic applications have, however, proved valuable; for example, the use of radiosodium for the differentiation of normal and restricted blood flow and for radiocardiography; radiophosphorus for determining the exact extent of a tumor mass during brain surgery; and radioiodine for preoperative location of certain brain tumors, for detecting disorders of thyroid gland function, and for locating thyroid cancer metastases. Diagnostic uses of radioisotopes are expected to increase, however, for two reasons: only small nonhazardous quantities of radioactivity are usually required, and an increasingly larger number of isotope-labeled compounds will become available. The manner in which some of these compounds are selectively absorbed by certain tissues, or are differentially metabolized, will no doubt prove to be of diagnostic value.

In medical therapy, radioisotopes have proved useful in relieving, though not curing, a limited number of disorders. Radiophosphorus has been used for treating polycythemia vera and chronic leukemia; radioiodine for treating hyperthyroid-

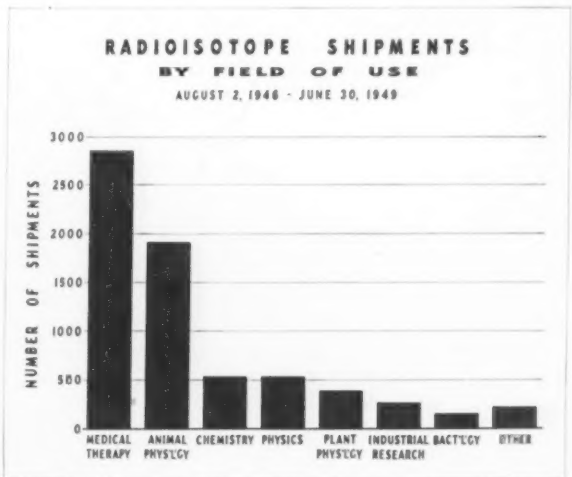

FIGURE 3.

* These publications may be obtained from the Superintendent of Documents, Government Printing Office, Washington 25, D. C.

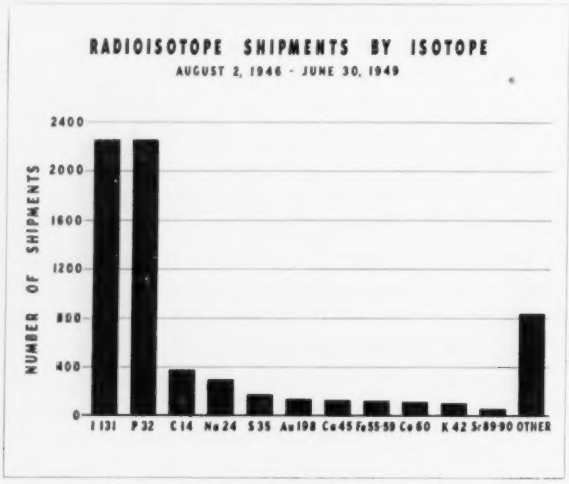

FIGURE 4.

ism and thyroid cancer metastases; radiogold for treating subsurface tumors of the lymphoid system and chronic leukemia; and radiocobalt as an interstitial source for treating accessible tumors. Also, very intense radiocobalt sources now available, equivalent in gamma ray output to over a pound of radium, should be valuable as teletherapy sources for treating deep-seated tumors.

It is possible also that isotope-labeled compounds may be used to a considerable extent to deliver radioisotopes and their accompanying ionizing radiation to specific tissues or organs. The use of such compounds will be limited to those into which the desired radioisotope can be incorporated and which will be selectively absorbed by the specific tissue or organ. Because of the much larger quantities of radioactivity needed in treatment, and the necessity for keeping total body irradiation at a minimum value, high selective absorption of the active material will be required.

As shown in Figure 3, a larger number of radioisotope shipments have been made for use in medical therapy (including diagnosis) than in any other field. The number of different projects utilizing radioisotopes in this field, however, is not as large as in some of the other fields. This is explained by the fact that the two isotopes most frequently used in medicine, radiophosphorus and radioiodine, have comparatively short half lives, and therefore several shipments may be made to complete a single investigation or case. A comparison of the number of radiophosphorus and radioiodine shipments with shipments of other radioisotopes is shown in Figure 4.

The potentialities of radioisotopes, together with their greatly increased availability, have stimulated an increasing interest in developing uses of these materials for the study, detection, and treatment of cancer. Because of this widespread interest, the Commission in April 1948 initiated a program for making available radiosodium, radiophosphorus, and radioiodine free of production costs to investigators proposing to use the materials in the study, diagnosis, or treatment of cancer and allied diseases. On February 25, 1949, this program was supplemented by making available free of production costs for use in cancer research all radioisotopes normally distributed from commission facilities. This phase of the distribution program has accounted for 2,059 shipments of isotopes of approximately 10 elements. Over 90 percent of these shipments have been of either radiophosphorus or radioiodine.

Use in plant physiology and agriculture. Isotope applications made thus far in the field of plant physiology fall largely into one of two categories, studies of photosynthesis and studies of phosphate fertilizer utilization. The first is a fundamental investigation into the mechanism of the process by which green plants, with the aid of sunlight, are able to convert water and carbon dioxide into complex sugars and other compounds. With radioactive carbon as a tracer, investigators have tried to determine the rate at which the process takes place and to identify the intermediate compounds formed. Although investigations are still incomplete, the tracer technique has enabled workers to identify some of the intermediates. Five compounds have been identified as having been formed within five seconds, and it also has been found that within ninety seconds at least 15 compounds are produced, including simple sugars containing 6 carbon atoms.

The studies on phosphate fertilizer uptake by various crops under different conditions of soil and climate are mostly being conducted by the United States Department of Agriculture in collaboration with state agricultural experiment stations. During the past growing season extensive field tests, using several different phosphate fertilizers labeled with radioactive phosphorus, have been carried out in more than 12 states on such crops as corn, potatoes, tobacco, sugar beets, alfalfa, oats, clover, rye grass, cotton, and peanuts.

Nutritional requirements and metabolism in plants of such elements as calcium, zinc, rubidium, and iron have also been studied with radiotracers. Metabolic disorders such as chlorosis and those caused by the parasitic action of fungi are readily studied by the tracer technique. Radioisotopes have also been used to study the action of plant growth regulators and the effects of radiation on plants.

Also of agricultural interest are radioisotope tracer studies in the field of animal husbandry. The tracer technique has proved to be particularly valuable in metabolism studies concerned with mineral requirements and nutritional deficiencies. Tracers have also been used in applied problems of entomology and pest control.

Use in physics and chemistry. Isotope applications in chemistry, like those in physics, are primarily of a fundamental nature. Tracer techniques have been used to study the mechanism and kinetics of exchange reactions, diffusion coefficients, oxidation, crystallization, and solubility. Chemists have also used tracers to determine the mechanism of many organic and biochemical reactions.

Physicists have used radioisotopes for studying nuclear characteristics such as disintegration schemes, the absolute energies of both beta and gamma radiation, beta ray spectra, nuclear spins, magnetic moments, and radiation absorption coefficients. They have also used radiomaterials to study and improve methods of radiation detection and dosimetry measurement.

Isotope studies in both chemistry and physics will undoubtedly have considerable influence on the scope and ultimate usefulness of isotopes in other fields of research. In physics, for instance, new knowledge of atomic nuclei is not only essential to the advance of atomic science, but also basic to the utilization of isotopes in all fields of research.

Use in industry. Industry's use of isotopes has to date been limited mainly because of a lack of the necessary facilities and specially trained personnel in industrial laboratories. Nearly fifty industrial research laboratories, however, have initiated radioisotope research.

Tracer isotopes have, for instance, been used in studying the polymerization and vulcanization of rubber, the dehydrogenation and aromatization of petroleum, and the mechanism and catalysis of reactions such as those involved in the production of synthetic gasoline. Metallurgists have made extensive use of radioisotopes in studying steelmaking reactions such as determining the mechanism and kinetics of slag-metal reactions, oxidation and crystallization, the molecular constitution of slag and metal baths, the diffusion coefficients of metals, the metallurgical activity of one element as influenced by the presence of other elements, and the concentration gradients in solid solutions. One of the most straightforward industrial investigations with radioisotopes has been the study of lubrication and wear phenomena associated with friction.

Several applications of the "gadget" or control type, such as radioactive thickness and height gauges, have been developed where the radiomaterial is used only as a source of ionizing radiation. Radioactive thickness gauges have been devised for the automatic gauging of paper, rubber, plastic, glass, and steel sheets and are already available on the commercial market from two different sources.

International distribution. The international distribution of radioisotopes by the United States is in keeping with the traditions of science. It also stems from the realization that, to assist other nations to help themselves attain better standards of health and living, they must be assisted in developing a vigorous activity in basic and applied science. Further, it must be recalled that in all fields American scientists are greatly indebted to the scientific achievements of scientists in other countries. In the basic discoveries of atomic energy this indebtedness is especially great. It is even more pronounced in the fields of radioactivity, nuclear transmutation, and isotope tracer techniques, wherein most of the "firsts" took place abroad.

Since radioisotopes are direct by-products of atomic energy, some concern might arise over the security aspects of their international distribution. Before distribution was undertaken, however, all conceivable security problems were given thorough and lengthy consideration by the Atomic Energy Commission and its advisory groups. The fact that radioisotopes were released for distribution in the United States without security restrictions, actually with the requirement to publish results, indicates that security is not a significant factor in their utilization.

Radioactive materials available for export are limited to 20 radioisotopes, selected because of their primary value for medical and biological applications. The radioisotopes are furnished only for fundamental scientific investigations and for medical research and therapy. All isotopes distributed —in fact, all radioisotopes—can be made with a cyclotron. Inasmuch as the major countries of Europe and some minor countries possess cyclotrons, radioisotopes are already available abroad. In fact, most of the requests received from abroad have been from groups who have previously used cyclotron-produced isotopes. The supplying of reactor-produced isotopes permits use by the many countries not possessing cyclotrons and makes possible use of the much larger quantities required for many medical and biological purposes.

Each country receiving isotopes agrees to re-

port semiannually to the U. S. Atomic Energy Commission on the progress of research done with the materials. In addition, each country agrees to permit qualified scientists, irrespective of nationality, to visit those laboratories where isotopes are being used. To date the following countries have made formal arrangements through diplomatic channels to the Department of State and have received radioisotope shipments: Argentina, Australia, Belgium, Brazil, Canada, Colombia, Denmark, Finland, France, Iceland, Italy, Netherlands, New Zealand, Norway, Peru, Spain, Sweden, Switzerland, Turkey, Union of South Africa, and the United Kingdom (Fig. 5). In addition, the following eight countries have completed the necessary arrangements, but have not placed orders: Chile, Cuba, Guatemala, India, Ireland, Lebanon, Mexico, and Uruguay. In the 22 recipient countries, the materials have been used in 150 institutions, many of which are world-renowned in the fields of research, education, and medicine. The impressive list of recipient institutions is published in the report *Isotopes—A Three Year Summary of United States Distribution,* referred to earlier.

It is expected that results obtained from foreign studies will provide valuable supplementary information to findings in the United States. For example, U. S. scientists investigating the possibility of using radioactive cobalt 60 as a substitute for radium in medical therapy have used the materials as interstitial needles and as teletherapy units. In Switzerland an investigator is making an entirely different approach. He first introduces a small rubber balloon by means of a catheter into the cavitary organ to be irradiated. The balloon is then filled *in situ* with the radioactive cobalt in solution. Upon completion of this work the advantages or disadvantages of the technique employed may be weighed against techniques being used in this country.

In Nigeria, British West Africa, radiostrontium has been used to tag the mosquitoes that are

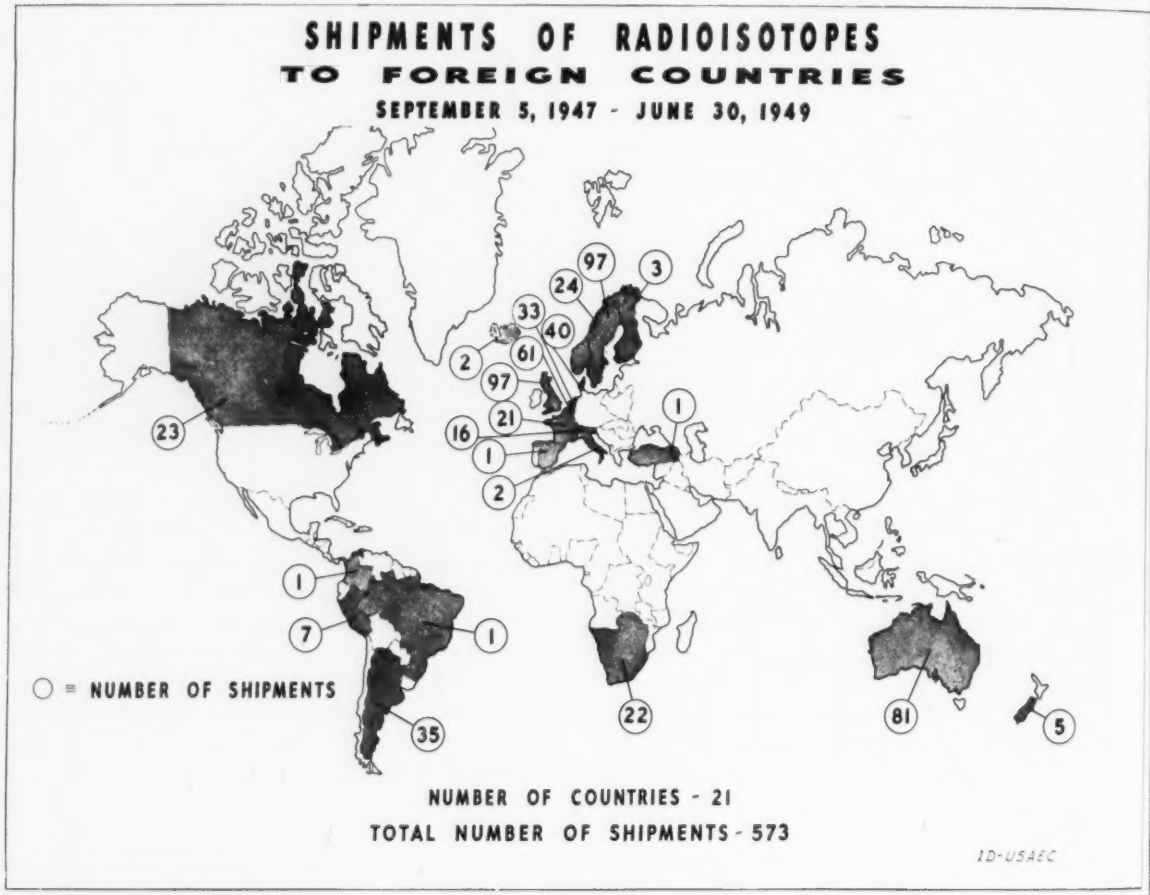

FIGURE 5.

carriers of yellow fever. The tagged mosquitoes are then used in studies designed to permit an estimation of the spread of yellow fever from a source of infection. In Australia, radiocobalt, radioiron, and radiozinc are being used to study the parasitic action of mistletoe on eucalyptus trees. Although the spread of yellow fever and the growth of eucalyptus trees are not serious problems in this country, the techniques used and the results obtained will certainly give valuable information to U. S. investigators using radiotracers in allied problems.

Compliance with the terms for obtaining isotopes has been excellent. Progress reports are submitted regularly, and the laboratories receive foreign visitors, including many from the United States. Good will and understanding have been evidenced by all foreign representatives dealt with in carrying out the program, and great appreciation has been shown by scientists and medical men who receive the isotopes. Although it is too early to expect extensive publication arising from the isotopes distributed, the results already reported are of high caliber and indicate that much value is certain to come from the researches conducted abroad.

Conclusions. The rapid growth in the isotopes distribution program may be attributed to a number of factors, including: (1) wider appreciation of the number and variety of potential isotope applications; (2) increased availability of isotopes and isotope-labeled compounds; (3) increased numbers of persons trained to handle and use radioactive materials; and (4) the AEC-sponsored program for supplying radioisotopes free of production costs for cancer research.

On the same bases, isotope utilization can be expected to increase in the future. A steady increase is expected as a result of both new types of research applications and new groups undertaking research with isotopes. A marked acceleration may take place if new wide-scale applications are developed for use in medical practice or industry. Future isotope utilization will also depend on the participation by private industry in various phases of the distribution program, for it is expected that the areas in which private enterprise can make valuable contributions will further expand.

The Commission will continue to encourage wider use of isotopes through its policies of extending the availability and usefulness of isotopes and isotopic materials, supporting educational programs in isotope techniques, and making available information on the feasibility and health-safety aspects of isotope utilization.

As tools of science and technology, isotopes will take their place with other long-established scientific instruments, and there should be no end to their growth in usefulness.

THE SCIENCE REPORTER

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THE SURGICAL TREATMENT OF CONGENITAL CYANOTIC HEART DISEASE

ALFRED BLALOCK, C. ROLLINS HANLON, and H. WILLIAM SCOTT, JR.

Dr. Blalock (M.D., Johns Hopkins, 1922), who, with Helen B. Taussig, developed the so-called blue baby operation, is professor of surgery and director, Department of Surgery, The Johns Hopkins University, and surgeon-in-chief of The Johns Hopkins Hospital. Drs. Hanlon (Johns Hopkins, 1938) and Scott (Harvard, 1941) are assistant professors of surgery at the Hopkins and surgeons in the Hospital.

AN UNDERSTANDING of the recent developments in surgical treatment of congenitally cyanotic children ("blue babies") requires a knowledge of the normal and abnormal structure and function of the human circulatory system. The normal structure of the heart and blood vessels was known to Galen in A.D. 179, but it was not until 1628 that William Harvey described the circulation of the blood from the heart through the arteries of the body and back to the heart by way of the veins. In the nineteenth century physiologists showed that the dark venous blood returns to the right side of the heart and is pumped out through the pulmonary artery to the lungs, where it is oxygenated. This bright-red blood returns through the pulmonary veins to the left side of the heart and is pumped out through the aorta and its arterial branches to the tissues of the body.

The circulation through the normal heart is shown in Figure 1. The blood in the right auricle and right ventricle, having given up its oxygen in the tissues, is dark in color, whereas the left auricle and ventricle are filled with bright-red oxygenated blood returning from the lungs. The septum between right and left sides of the heart prevents mixing of the venous and arterial blood. Blood is propelled from the thin-walled auricles into the heavily muscled ventricles through one-way valves, which prevent regurgitation into the auricles when the ventricles contract. As a result, contraction of the ventricles drives the blood into the aorta and the pulmonary artery, where other one-way valves maintain the forward progress of the circulation.

For a better understanding of congenital circulatory derangements one must consider the fetal circulation (Fig. 2). Before birth the lungs are collapsed, and the fetus derives its oxygen from the mother. Oxygenated blood returns from the maternal tissues through the vein in the umbilical cord to the right auricle of the fetus. Some of this blood passes directly into the left auricle through an opening in the septum between the auricles, the "foramen ovale." The remainder passes into the right ventricle and is ejected into the pulmonary artery. Not all the blood in the pulmonary artery reaches the lungs, however; a large proportion of it is shunted through the "ductus arteriosus," which is a tubular connection between the pulmonary artery and the aorta. By reason of the flow through the foramen ovale and the ductus arteriosus, blood from both sides of the heart is pumped into the systemic circulation.

After expansion of the lungs at birth, there is an adjustment in the pressure relationships of the two sides of the heart. The foramen ovale closes, as does the ductus arteriosus. As a result all the blood in the right auricle passes into the right ventricle and thence to the lungs (Fig. 2). Thus the normal postnatal circulatory plan is established.

In some instances the ductus arteriosus fails to close. This leads to serious derangement of the

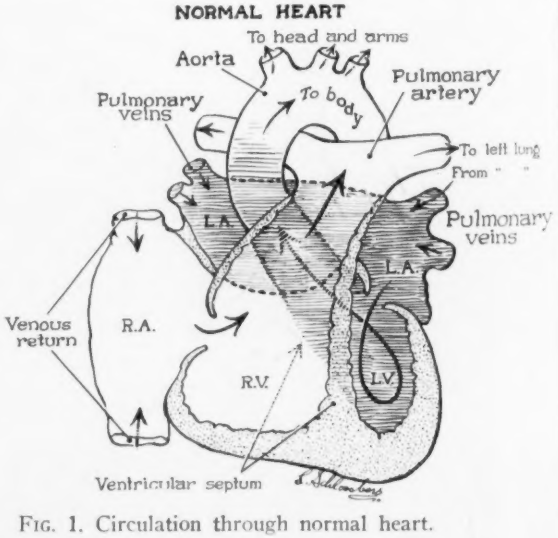

FIG. 1. Circulation through normal heart.

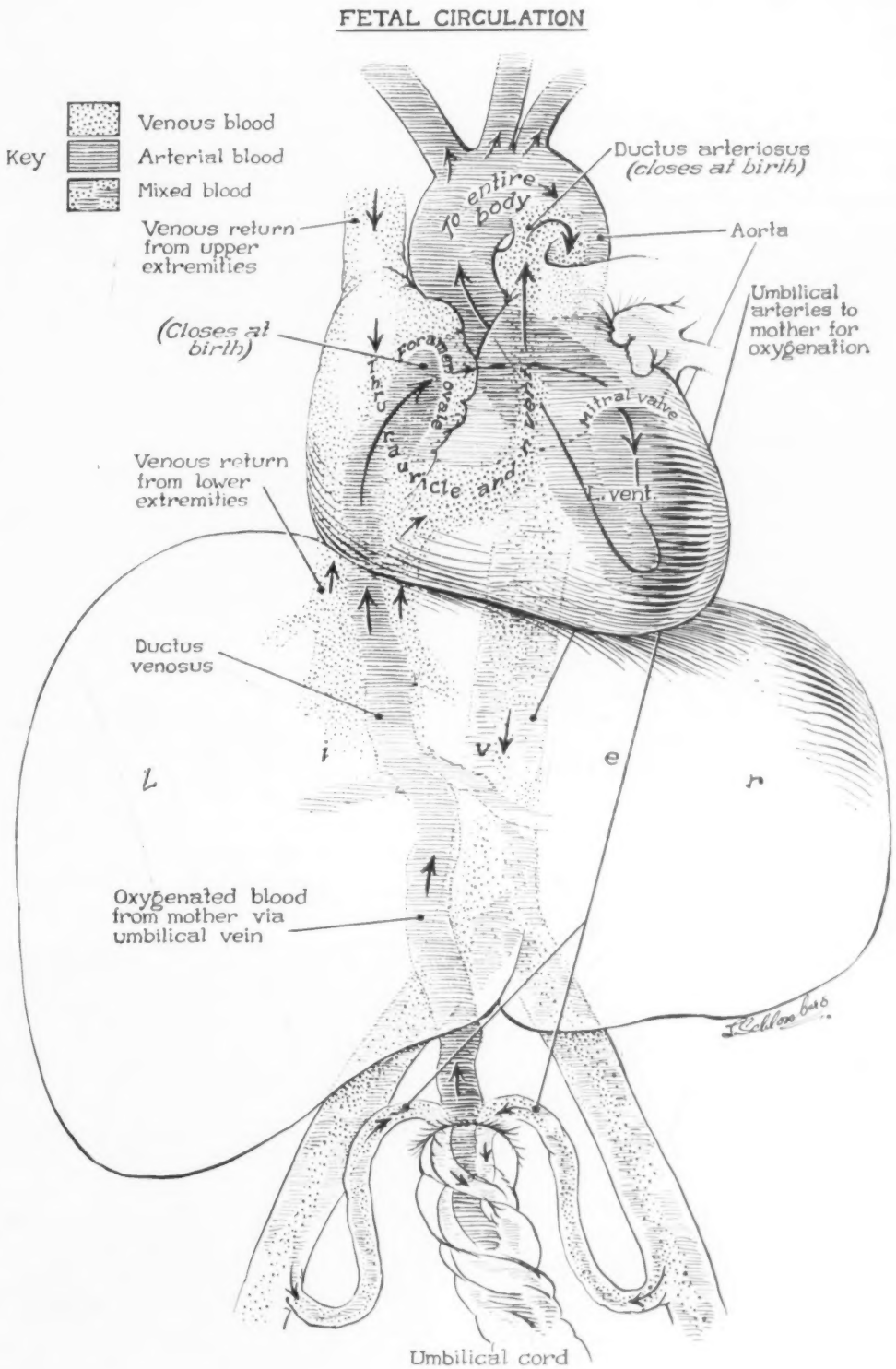

FIG. 2. Course of circulation in fetus. With closure of the foramen ovale and ductus arteriosus the normal adult circulation is established.

circulatory plan. The persistent ductus arteriosus represents a form of congenital heart disease in which the developmental error is late in occurrence; in contrast to this, most congenital abnormalties of the heart result from aberrations that occur early in embryonic life. Some of these are so severe as to be incompatible with extrauterine life, and others permit existence with handicaps of varying degree. The cause of these embryonic errors is not always clear, although it has recently been shown that certain virus infections in the mother during the early stages of pregnancy give rise to cardiac defects or to other abnormalities.

Congenital malformations of the heart may be divided into two groups, based on the presence or absence of cyanosis. Cyanosis (*kuavos,* "dark blue") is a blue or dusky color of the lips and skin due to the presence of an abnormally large amount of unoxygenated hemoglobin in the blood of the superficial vessels of the integument. There are normally about 15 grams of hemoglobin in 100 cubic centimeters of blood. It has been shown that at least 5 grams of hemoglobin per 100 cubic centimeters of blood must be unoxygenated before cyanosis is apparent. Thus it is clear that cyanosis is a sign of severe oxygen deficiency.

As a result of the low oxygen saturation of the blood, cyanotic patients are frequently retarded in growth and development and are markedly limited in their physical activities. Many of them are unable to walk more than a few steps without great fatigue and shortness of breath. The body attempts to compensate for the chronic oxygen deficiency by producing an excessive number of red blood cells, a condition known as polycythemia. Whereas the normal person has 4.5–5.0 million red corpuscles per cubic millimeter of blood, cyanotic individuals may have 8 or even 10 million red blood cells per cubic millimeter. This makes the blood more viscid than normal. Another peculiar feature in these patients is the phenomenon of "clubbing" of the fingers and toes (Fig. 3). Although this bulbous thickening of the digits is characteristic of congenital cyanotic heart disease, it is not invariably present. Moreover, it may be seen in various other disturbances of pulmonary function that cause lowered oxygen saturation of the blood.

The structural defects in the heart that produce cyanosis are numerous. In most cases the great vessels arise from the ventricles in an abnormal manner. Frequently in these malformations only a small portion of the venous blood reaches the lungs, and a large volume of venous blood is pumped directly into the systemic circulation.

The most common malformation of the heart giving rise to cyanosis is called the tetralogy of Fallot. Fallot, a French pathologist, described the four cardinal features of the anomaly in 1888 (Fig. 4). On examining such a heart one finds narrowing, or stenosis, of the pulmonic valve or of that part of the right ventricle leading into the pulmonary artery. The base of the aorta lies farther toward the right side of the heart than normal, so that it overrides the septum between the right and left ventricular chambers. Furthermore, there is an abnormal opening high in this septum between the ventricles near the origin of the aorta. And, finally, there is thickening of the right ventricular muscle as a result of the strain imposed by the resistance of the narrow valve to the pumping action of the ventricle.

It may readily be seen from the diagram (Fig. 4) why patients with Fallot's tetralogy have cyanosis. Because of the narrow pulmonic valve, only a small proportion of the blood in the right ventricle can pass into the pulmonary artery to be oxygenated in the lungs. The remainder is pumped into the aorta, either directly from the right ventricle or by way of the interventricular septal defect into the left ventricle and thence into the aorta. Thus there are at least two factors operating to cause cyanosis in these patients—one being inability to propel a normal volume of blood into the lungs for oxygenation, and the other the passage of a large volume of dark venous blood from the right ventricle into the left ventricle and aorta without its being oxygenated in the lungs.

As has been mentioned, children with cyanosis are greatly restricted in their activity; moreover,

FIG. 3. Hands of patient with congenital cyanotic heart disease (tetralogy of Fallot). The "clubbing" of the fingers may disappear after operation has relieved the cyanosis.

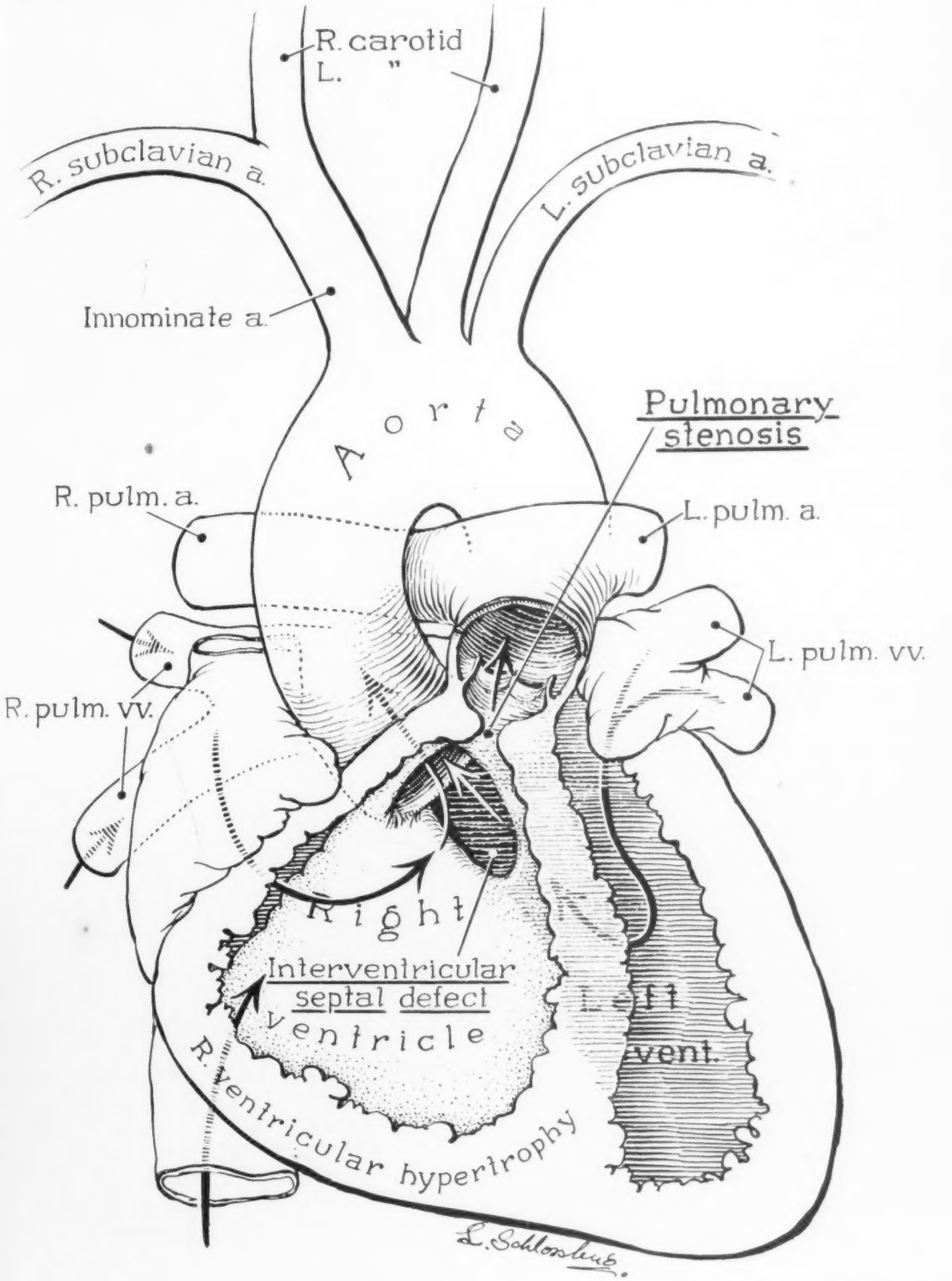

FIG. 4. Course of circulation in tetralogy of Fallot. The four features of this cardiac malformation are: (1) pulmonary stenosis; (2) interventricular septal defect; (3) shift of aorta to right; and (4) hypertrophy of wall of right ventricle.

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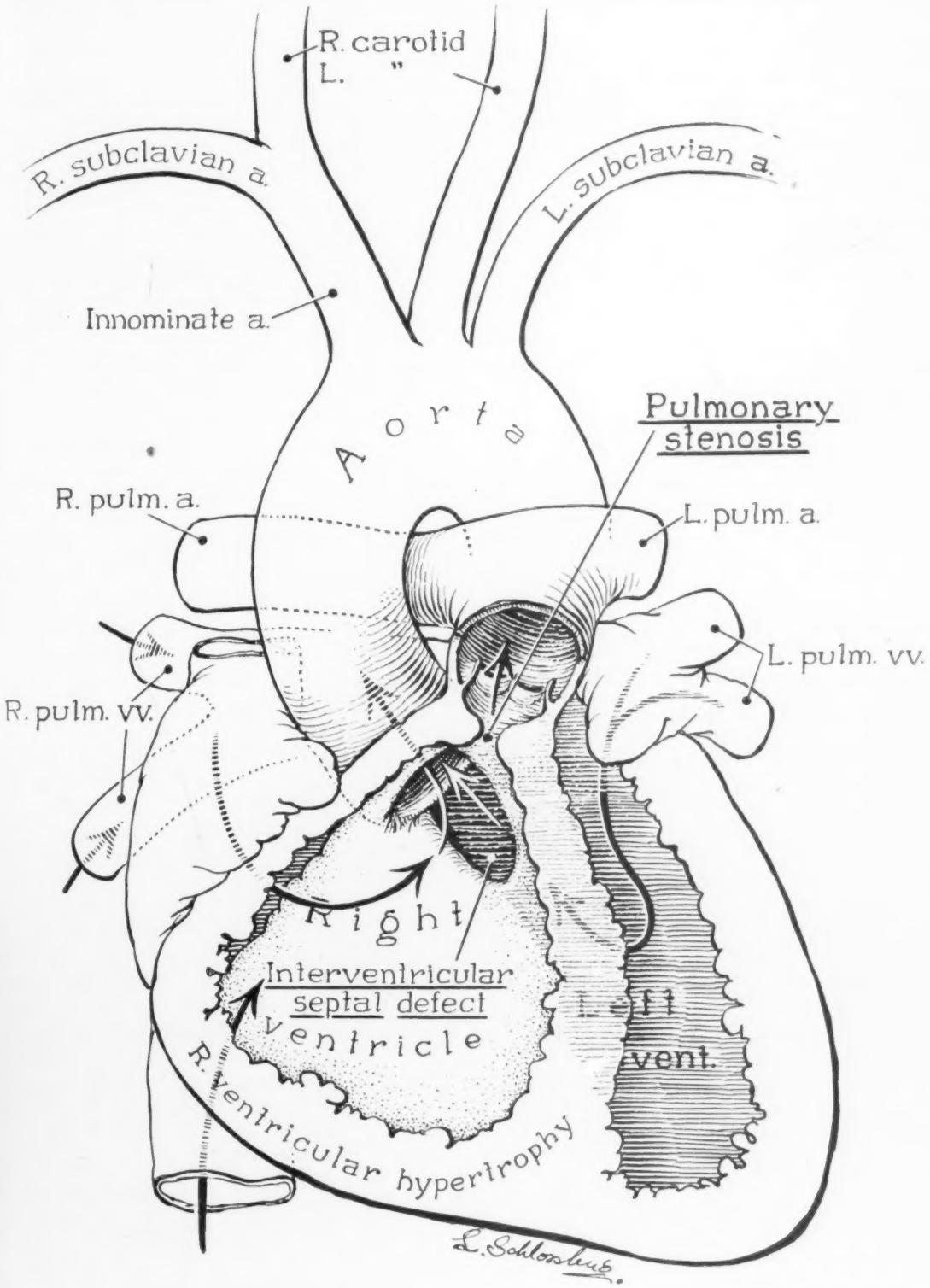


FIG. 4. Course of circulation in tetralogy of Fallot. The four features of this cardiac malformation are: (1) pulmonary stenosis; (2) interventricular septal defect; (3) shift of aorta to right; and (4) hypertrophy of wall of right ventricle.

they are much more prone to infections than are normal children. In addition, the increased viscosity of the blood may lead to clotting in the vessels of the brain, resulting in paralysis similar to that occurring in "strokes" in the aged. The defective parts of the heart may be the site of localized bacterial growth, which leads to generalized infection of the blood stream. All these factors combine to lower sharply the life expectancy of these individuals. Most of them die before reaching adult life, many during infancy or early childhood. In rare instances a person with such a defect may live to a relatively advanced age, the most famous being Henry Gilbert, the distinguished American music composer, who suffered from the tetralogy of Fallot but lived until his sixtieth year.

It is difficult to establish an exact diagnosis of the specific defect of the heart present in a "blue baby." Physical examination shows cyanosis, general underdevelopment, and clubbing of the fingers and toes. Auscultation with the stethoscope will frequently detect a murmur which blurs the clear quality of the heart sounds, but differentiation of the various malformations requires careful study of the heart shadow under the fluoroscope. A typical case of the tetralogy of Fallot may be diagnosed merely by physical examination and fluoroscopy. The more complicated malformations, however, frequently require elaborate studies. These include the electrocardiogram, catheterization of the cardiac chambers, and angiocardiography. The electrocardiogram records a tracing of the changes in electrical potential that take place with the contraction and relaxation of the heart. Catheterization studies are made by threading a fine sterile tube into an arm vein and passing it along the vein directly into the heart, where its position may be determined by means of the fluoroscope. Samples of blood from the heart chambers are taken for oxygen determination, and pressures may be measured in various parts of the heart by the use of special manometers. These determinations provide clues to the specific malformations that exist. Fluoroscopy in conjunction with manipulation of the intracardiac catheter often permits direct demonstration of abnormal openings between the right and left sides of the heart. Angiocardiography is a method of visualization of the heart and great blood vessels using the rapid intravenous injection of a radiopaque substance such as iodopyracet, followed by roentgenograms in rapid sequence.

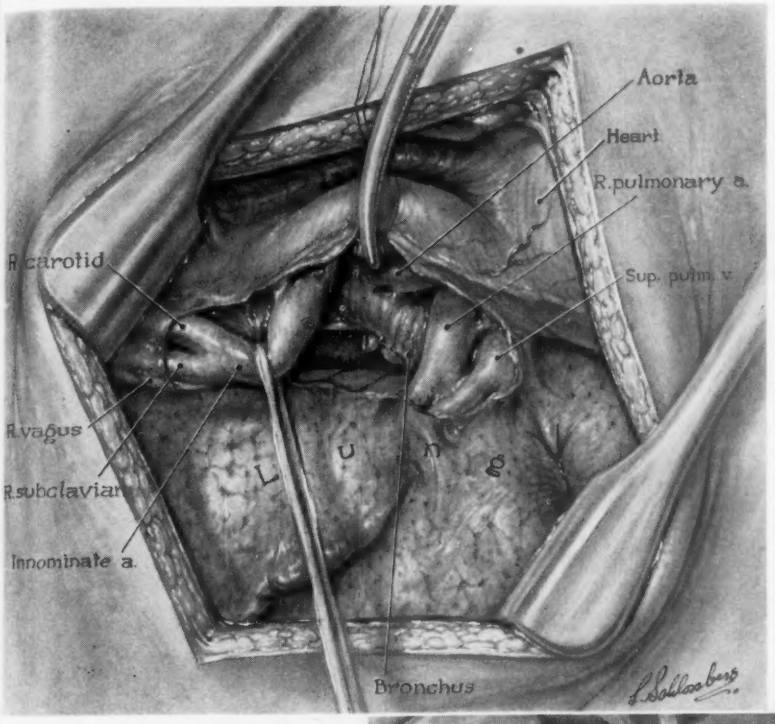
By these technics the malformation in a patient with cyanosis may be diagnosed with considerable accuracy. Once diagnosed, the problem of treatment has until recently been largely unsolved. Even with the best medical management these patients were doomed to a life of invalidism. The circulation to the lungs is not only reduced but it cannot be increased to meet the extra demands imposed by exercise. The relatively greater oxygen lack that occurs with exercise leads to extreme cyanosis and often to loss of consciousness. Patients not infrequently die during such an attack. The greatly reduced life expectancy of patients with congenital cyanotic heart disease emphasizes the need for a method of treatment.

The surgical attack on this problem has been based largely on efforts to increase the amount of blood flowing through the lungs, the need for which was shown by Blalock and Taussig. The beneficial results of increased pulmonary flow in patients with pulmonic stenosis are well demonstrated by the small number of individuals with the tetralogy of Fallot who have in addition a persistent ductus arteriosus. Some of these relatively fortunate patients have had no cyanosis and little or no limitation of activity.

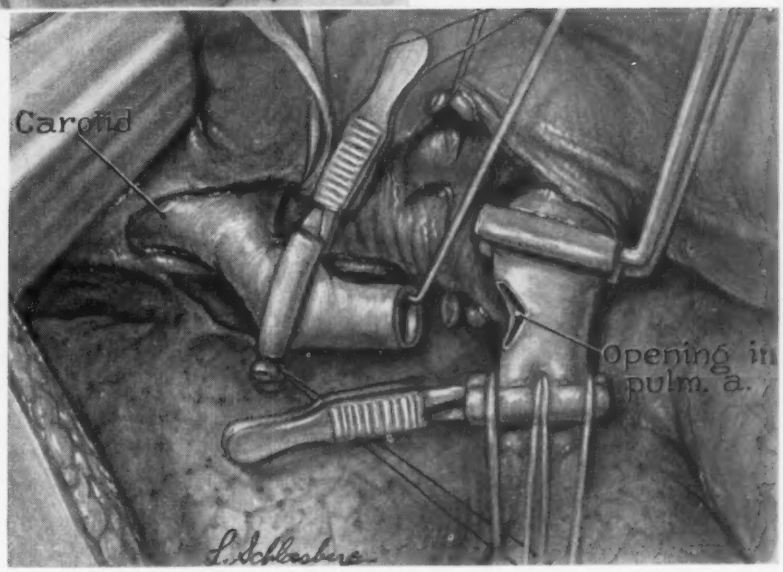
If the ductus arteriosus remains open in a child with congenital pulmonic stenosis, it provides a channel whereby a large amount of blood from the aorta may enter the pulmonary artery beyond the point of narrowing. This blood passes to the lungs for oxygenation, thereby increasing tremendously the amount of oxygenated blood returned to the heart for distribution to the tissues.

Operations on patients were preceded by experiments on animals in which cyanosis was produced and attempts made to reduce or to abolish it. Cyanosis was produced by removal of lobes of the lungs in anesthetized dogs, followed by an anastomosis of the proximal ends of the arteries to the veins of the lobes. Thus some of the improperly oxygenated blood from the right ventricle would return to the left side of the heart without having picked up any oxygen in the lungs. Cyanosis was the result. After considerable trial and error for nearly two years, it was found that an anastomosis between a branch of the aorta and a pulmonary artery (artificial ductus arteriosus) would cause a lessening of the cyanosis. These experiments supplied the basic concept of treatment and afforded a means for perfecting the technic for this type of vascular surgery.

Even after completion of the basic experiments and the attainment of proficiency in the operative technic, there was hesitancy about operating on the cyanotic patient. There was fear that the cyanotic patient would not withstand anesthetization for the period of time necessary for the per-



A: Dissection of vessels in right chest has been completed. Note right pulmonary artery and right subclavian artery.



B: The subclavian artery has been divided and is ready to be sewed into the side of the pulmonary artery.

FIG. 5. Operation for relief of pulmonic stenosis.

formance of the operation. There was especial concern that the period during which one of the two pulmonary arteries would have to be occluded could not be tolerated. Subsequent experience has revealed that most of the cyanotic patients withstand anesthetization remarkably well. It is true that they usually become more cyanotic when one of the pulmonary arteries is occluded, but rarely does such a maneuver result fatally. In addition to the above worries, it was feared that the patient's arm might become gangrenous as a result of the sacrifice of the subclavian artery in the performance of the anastomosis between the systemic and pulmonary circulations. There has been no serious impairment of circulation to the arm in any of our patients, however.

Before describing the operation and giving the results on patients, it must be emphasized that patients with the tetralogy of Fallot are cyanotic not only because the artery to the lungs is constricted at its point of origin from the heart but also because the main artery to the body (the

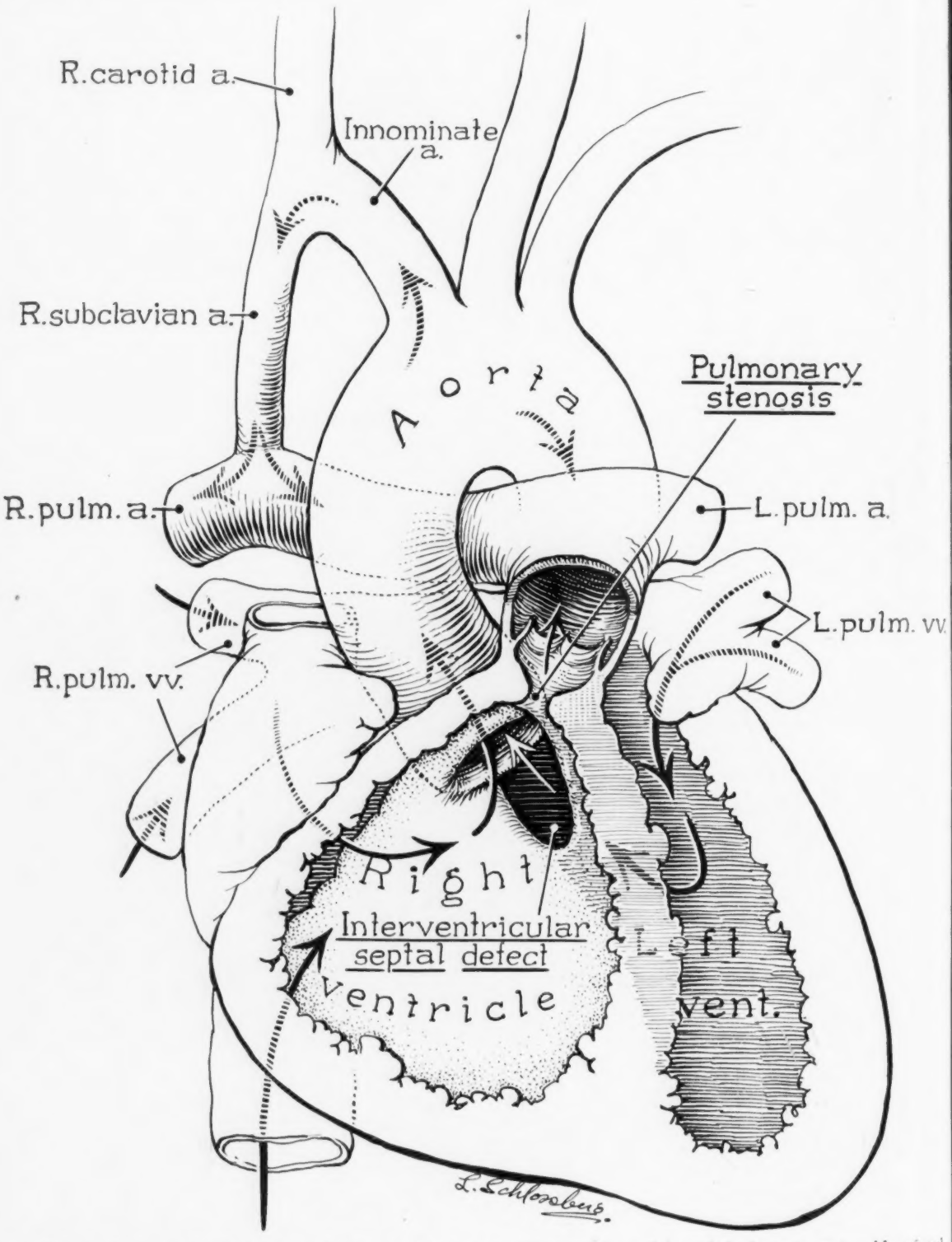


FIG. 6. Course of circulation in tetralogy of Fallot after anastomosis of right subclavian artery to side of pulmonary artery. This increases blood flow to both lungs.

aorta) contains blood that is inadequately oxygenated. The purpose of the operation is to cause some of the blood in the aorta to flow through the lungs, where it may take up oxygen. Fortunately, the blood pressure in the aorta is quite high, and the pressure in the pulmonary artery is low, so that a large quantity of blood will flow to the lungs through a relatively small communication between aorta and pulmonary artery. An opening of large size may result in heart failure.

The operation on patients is carried out under intratracheal cyclopropane or ether anesthesia, which provides maximum oxygenation of the patient's blood while allowing maintenance of quiet, even respirations during the procedure. A transverse incision is made on the front of the chest from the midline out into the armpit, and the chest cavity is entered between two of the upper ribs. The lung on the side of the incision is temporarily deflated, and the artery leading to it is carefully dissected free (Fig. 5*A*). The subclavian branch of the aorta is exposed, and an occluding clamp is placed across its base. This artery is ligated several centimeters from its origin and divided. The cut end of the subclavian artery is then turned down to the side of the pulmonary artery. Blood flow through the pulmonary artery is checked temporarily by clamps, and a small incision is placed in its wall (Fig. 5*B*). The open end of the subclavian artery is then sewed with fine silk into the side of the pulmonary artery. The constricting clamps on the two vessels are released slowly after the anastomosis is completed. If an accurate union has been made, there is a little or no leakage of blood, since fibrin quickly seals the suture line. A palpable vibration, or "thrill," can be felt in the pulmonary artery after the clamp on the subclavian artery is released. This indicates the greatly increased flow of blood through the pulmonary artery because of the anastomosis (Fig. 6). The lung is then reexpanded, and the incision in the chest wall is closed. There are several variations of the operative technic. One of these is a side-to-side anastomosis between the aorta and the pulmonary artery, as described by Potts and his associates.

The majority of patients withstand the operative procedure remarkably well. Oxygen and penicillin are administered postoperatively. Within a week most patients are able to be out of bed and are generally allowed to leave the hospital about two weeks after the operation.

With the circulation to the lungs increased by a suitable anastomosis, the color of the patient improves immediately in most cases. The improvement does not reach its maximum, however, until the elevated red blood cell count approaches normal; this usually requires two to three weeks or longer. The clubbing of fingers and toes is more persistent but disappears entirely in many patients. The most important alteration is the ability of the patient to take part in various activities. The degree of improvement in this respect varies, but in most cases it is very gratifying. Some of the patients who could walk only a few steps before operation are now able to run or to walk long distances without undue fatigue. Many patients cannot be distinguished by their activities from normal children.

During the past four and one half years, the group at The Johns Hopkins Hospital has operated on 840 patients who were suspected of having the tetralogy of Fallot or a slight variation of this combination of defects. Hundreds of similar patients have been operated upon elsewhere. The age of the patients in our series has varied from six weeks to forty-four years, the great majority being children. Including the atypical cases, approximately one patient in six has died during or since the operation. During some periods, as many as forty-four consecutive patients have been operated on without a death. The improvement in the survivors varies, but in the majority it is very great. The time which has elapsed since the first of these operations is too short to permit an evaluation of the ultimate results. One may state with certainty, however, that many of the patients are leading much happier lives.

Our discussion has been limited largely to a consideration of treatment of the tetralogy of Fallot (pulmonic stenosis) because this is the most common type of congenital heart disease accompanied by cyanosis, or blueness, and because considerable progress has been made in its therapy. Satisfactory surgical methods for correction of several other types of congenital heart disease are well established. Notable among these are the operations for patent ductus arteriosus and for constriction ("coarctation") of the aorta. These corrective procedures, in common with the operation for the tetralogy of Fallot, are performed outside the heart itself. Various investigators are now working on methods for treating other forms of heart disease, both congenital and acquired, which require actual intracardiac surgery. Some progress is being made in this regard.

Figures 4, 5, and 6 used by permission of *Surgery, Gynecology, and Obstretics.*

OF DIGITAL COMPUTERS CALLED BRAINS

WARREN S. McCULLOCH and JOHN PFEIFFER

Dr. McCulloch, professor of psychiatry at the University of Illinois College of Medicine, situated in the Illinois Psychiatric Institute, Chicago, has long been a student of the operation of the nervous system, including the brain. This article is based on a speech made by Dr. McCulloch before the American Institute of Electrical Engineers last January. Mr. Pfeiffer is a well-known science writer who is a member of the Board of Editors of Scientific American.

IT HAS been said that since the days of Helmholtz no man can understand all science. If by this is meant knowledge of all descriptive details, it is increasingly true. But there are many signs that at the level of theory the most remote of disciplines have developed central ideas that are pulling them together. The wildest speculative analogies of a generation ago turn out to be similar problems in dissimilar materials. What is learned in one field today furnishes a profitable attack in the remote tomorrow.

One of the most important notions that has proved its value in many sciences may be traced back to the atoms of Democritus. But the concept of ultimate units had its first bearing on modern science when the discovery that gases combined chemically by volume in the ratio of small whole numbers marked the transition from alchemy to chemistry. Unless you compare the writings before Dalton proposed the atomic hypothesis and before Avogadro computed the number of molecules per gram molecular weight with all that comes afterwards, it is difficult to appreciate how great a revolution this idea can produce in any science.

The same idea found its way next into biology when, to explain Mendelian inheritance, we invented genes as atomistic carriers of prescriptions for the adult form. As a result, this part of biology is today perhaps its cleanest discipline. The cellular hypothesis—especially the neuronal hypothesis—quantized living things in a way germane to our argument. Then physics felt its impact, and the mathematics grew up to handle it, so that we live not in an atomic world in the sense of the chemist, but in the particularized world of the nucleonic physicist—a world ultimately composed of a very large number of a very few kinds of particles, with even their energies and possible positions atomized. In this world it seems best to handle even apparent continuities as some numbers of some little steps.

Recently, the notion of ultimate units has been applied to the communications field and has opened the way to important advances in the design of calculating machines and to a better understanding of the working of our brains. The art of communication is very old, but the science is very new. When we reduced our speech to syllables and built an alphabet, we took the first great steps in the right direction, for our letters are comparable to the atoms of chemistry. All communication is a matter of information conveyed by signals, and the next great step was atomic signals. The bulk of our signals were and are analogical. They are signals in which a value of some continuously varying quantity stands for the message, like the current in your telephone or the distance on your slide rule. The difficulty with such signals is that their precision is limited to about six significant figures at best, and no combination of devices can increase that precision; hence, the information that analogical signals can convey is inadequate for many of the requirements of modern science.

There is another kind of signal in which some variable is restricted to a small number of possible values at distinct times or separate places. The message is the order or number of these possible quantities, as in the case of the dots and dashes of telegraphy and the coin of the realm. In the simplest case, this reduces to the presence or absence—call it one or zero—of something at an appointed place or time. This is the famous binary digit, now nicknamed "bit." Any number can be written in bits as well as in the decimal system; in the binary system, 1, 2, 3, 4, and 5 become simply 1, 10, 11, 100, 101. Since a device does not have to be very sensitive to distinguish between a "one" signal and a "zero" signal, precise workmanship is unnecessary. Every time you send a binary message through a relay it comes out as

good as new, so that you can combine devices that use bits to obtain an extra bit in any array—and a corresponding increase in precision—at no extra price per bit. It is interesting that any letter on this printed page, being one of some 60 items, can be selected from the printer's tray by six all-or-none binary decisions—and that such a six-bit item is a molecular signal, whose six decisions are its ultimate particles. In this quantizing of signals the science of communication finds its appropriate atoms.

The use of the binary digits 0 and 1 happily conforms to what is perhaps the simplest part of logic. We reduce the logic of relations to the logic of classes when we consider only one relation, membership in some class. We reduce the logic of classes to the logic of propositions when we consider membership in only one class, namely, the class of truths. We then assign the value 1 to anything if it is true—if not, 0. In fact, it was Boole's discovery of this property that led him to the attempts to construct a logical machine. His mathematical theory of logic has just been reprinted, but, meanwhile, largely through the work of Whitehead and Russell, much of mathematics has been reduced to logic. Thus, today one speaks of any device for communication which performs its computations by these discrete signals indifferently as either a digital or a logical machine. And all large modern computing machines are principally digital.

In a certain sense, the scope of any communication device, including a computing machine, is ultimately determined by the number of distinct states that it enjoys. A device of n binary component organs (nerve cells, electromagnetic relays, vacuum tubes), each of which can be one of two possible positions at any given time, has 2^n possible states. Now, since the world is composed of particles which can only be in discrete states, we could treat all machines as if they were digital devices if we could make full use of all these particles in their states. But we cannot weigh to one electron more or less, or measure the position of a pointer to the least possible jump of nuclear dimensions. We can only deal with these statistically and, when we do so, we ignore the theoretically distinguishable states of the system in the average. The same goes for our macroscopically digital devices, when we combine their components intentionally to secure averages or suffer stray fields from the operation of one component to influence another. The average may look more precise, but its accuracy ends with the last significant bit. All analogical devices are ultimately digital devices, averaged whether we will or no.

I

The human brain consists of, say, 10^{27} or 10^{28} of the ultimate particles of the physicist, and one might describe how it works by stating how those particles behave—and we may ultimately be able to do so. But for our purposes it would be about as silly as to describe a chair by the motions of its component particles. The whole development of the anatomy and physiology of the nervous system suggests that we can simplify the problem. As a device for handling signals, the brain can be conceived as an ensemble of nerve cells or neurons, which act quasi-independently. There are some 10^{10} of them, and they constitute about a twentieth of the total volume of the central nervous system. So, on the average, each is made up of some 10^{16} or 10^{17} ultimate particles. To quantize the neurons cuts the complexity of the problem about in half. We shall therefore consider these cells as components and their all-or-none nervous impulses at least binary signals. Thus, regarding the anatomy of the nervous system as if it were a wiring diagram and the physiology of the neuron as if it were a component relay of a computing machine, we shall describe the brain in terms thoroughly familiar to the electrical engineer whose business is communication. For our object is to set up working hypotheses as to the circuit action of the central nervous system as a guide to further investigation of the function of its parts, and as a scheme for understanding how we know, think and behave.

Let us replace each neuron by a relay having its own battery, charged by a series of chemical reactions converting sugar and oxygen to carbon dioxide and water. When the supply of these materials fails, or the reactions are obstructed, the voltage of the relay ceases to be in the proper range, and the circuit action goes wrong in any one of many ways. Doctors generally call the resulting disorders of thought and behavior "functional" psychoses, because they disappear when the chemical conditions are again such as to produce proper voltages at the proper places. Some of these conditions have been treated successfully by producing an epileptic fit, either with drugs or by the passage of alternating currents through the brain. The fit discharges the batteries so frequently that they are for a time exhausted. During this period and the early part of the restoration of the voltage, the brain uses 8–80 times as much energy as it usually needs.

Even so, it takes many minutes for all voltages to be near enough to normal to restore a semblance

of the brain's regular circuit action. We know it is the voltage that matters, not the particular reactions that produce it, for a nerve deprived of oxygen and so at the wrong voltage fails to transmit signals. But as soon as its voltage is restored from an external battery—say, a dry cell—it again transmits its signals properly. Except during fits on the one hand and comas on the other, the brain requires a nearly constant supply of energy which, once it is spent, must be removed as so much heat. In fact, the brain heats the pint of blood that flows through it per minute a little less than 1 degree Fahrenheit. In electrical units this is a little under 24 watts. So long as this power is supplied and the heat removed, neither the neurophysiologist nor the communication engineer need think in terms of energy.

Instead, it is best to think in units of information conveyed by electrical impulses, the all-or-none signals of the neurons they traverse. These cells vary downward in size from giants that have a body, say, two thousandths of an inch in diameter, fronds, or dendrites, about a tenth of an inch long, and a tap root, or axone, perhaps a thousandth of an inch in diameter and up to six feet long. The metabolic battery of every cell keeps its outside about a tenth of a volt positive to its inside until it is stimulated. It can be stimulated anywhere by driving its outside negative, thereby starting a current which flows from near-by positive parts of its surface into the excited region, partly recharging that region, but also draining the region whence it came, until it becomes a sink for current from the surface beyond it. Thus, the pulse of current travels along the neuron, turning itself inside out like a smoke ring as it goes.

For electrical purposes the cell membrane may be regarded as a leaky capacitor kept locally charged by the metabolic battery. The pulse therefore travels at a rate determined by the distributed resistance, distributed capacity, and distributed source of voltage, so that we may think of the entire neuron as if it were simply a distributed repeater. From the circuit constants of the neuron we would expect a maximum impulse speed of 150 yards a second in fat fibres and a minimum of, say, a foot a second in thin fibres—and so it is. Since the fast fibres usually connect remote places and the slow near places, the effect of distance on temporal relations is generally minimized. The nervous impulse rises to its peak in about a tenth of a millisecond and falls away in several tenths, after which the neuron may conduct an impulse like the first.

But if the impulses are repeated in quick succession, their voltage declines and it becomes harder to produce them. When impulses arrive upon a neuron, there is a delay of about half a millisecond before its own impulse starts; physiologists call this time the synaptic delay. To trip a neuron, several pulses must arrive upon it over separate axones within one or two tenths of a millisecond, and, finally, it may be prevented from responding at all by impulses arriving in its vicinity some half a millisecond before those that would otherwise trip it. From electrical records of brain and nerve we know that some neurons do conduct trains of 200 pulses a second, but 20 a second is more nearly the usual upper limit, so that they are called on to respond somewhere between a tenth and a hundredth as often as they could.

Judging by speed of response, neurons fall into the middle range of man-made relays. They are about a thousandth as fast as vacuum tubes, about as fast as thyratrons, but faster than electromagnetic and mechanical devices. Because they are much smaller than electronic valves, though the voltage gradients are about the same, they take lower total voltages and less energy. A computer with as many vacuum tubes as a man has neurons in his head would require the Pentagon to house it, Niagara's power to run it, and Niagara's water to cool it. The largest existing calculating machine has more relays than an ant but fewer than a flatworm. Neurons, cheap and plentiful, are also multigridded, the largest having upon them thousands of terminations, so that they resemble transistors in which the configuration of electrodes determines the gating of signals.

Moreover, since neurons are mechanically rather stable and repair themselves, they have a long effective life. We get no new ones from the day we are born until we die. Every neuron in our head is as old as we are, and most of them are still serviceable. Of course, they may be killed by injury, accident, germs, want of sugar or of oxygen, or failure of their blood supply. When this happens to enough of them in the proper places, we suffer neurological diseases and what we call "organic" psychoses, meaning that the damage can be found in the dead brain.

So far as we can discover, Shannon was the first to apply Boolean algebra to nets of relays. But he was principally interested in whether circuits were open or closed, rather than in the time of opening and closing. In complete ignorance of his work, Pitts and McCulloch constructed a calculus for the impulses of nervous circuits, which has subsequently been used in teaching the gen-

eral theory of digital computing machines. The calculus is very simple. It is made from the calculus of atomic propositions of Whitehead and Russell, by treating the impulse of a neuron as a proposition embodied in the signal of a particular neuron at a particular time—and that time is measured in synaptic delays. For example, $N_7(t\text{–}3)$ means that neuron number seven transmitted an impulse three synaptic delays before an arbitrary origin of time. If two neurons are connected so that N_1 has an impulse at time t only if it received an impluse from N_2 at the time t–1, they write $N_1(t) \supset N_2(t\text{–}1)$, in which the horseshoe $\supset$ can be read "implies" or "only if" for this, the sequential relation of nervous signals, is what in logic is called material implication.

Three contemporaneous relations of signals are clearly demonstrable within the central nervous system. For neurons that can be tripped by either of two other neurons, Pitts and McCulloch write $N_1(t) \supset .N_2(t\text{–}1) \; v \; N_3(t\text{–}1)$. In this expression the v is an abbreviation of the Latin *vel*, the "and/or" of legal documents. It is usually called the disjunction of its arguments. For neurons that in physiological parlance are said to require summation—that is, neurons that will transmit a signal only if signals from two or more sources arrive on them practically simultaneously—they write $N_1(t) \supset .N_2(t\text{–}1) .N_3(t\text{–}1)$. The dot between $N_2(t\text{–}1)$ and $N_3(t\text{–}1)$ means that both must have happened; it can be translated as "and." It is usually called the conjunction of its arguments. Finally, for neurons which can be tripped by an impulse from one neuron unless prevented by an impulse from another, they write $N_1(t) \supset .N_2(t\text{–}1) .\sim N_3(t\text{–}1)$, in which $.\sim$ may be read "and not," stands for conjunction with negation of its arguments.

These three expressions would be insufficient to generate the whole of the calculus of propositions unless there is a steady source of impulses or a neuron that regularly fires spontaneously, like the local oscillator in a heterodyne circuit. Then they are more than sufficient. Using this calculus, Pitts and McCulloch proved that even nets devoid of closed paths could, like Thüring's machine, compute any computable number or—what amounts to the same thing—could have a single signal in a specified neuron which implied any arbitrarily selected figure in the input of an appropriate net. In such a net the logical relation of implication extends backward in time and backward toward our sense organs, so that what happens in our heads implies the world that did impinge upon our sense organs. In the world of physics, things either happen or they do not, and that is all there is to it. But in communication the simplest things are signals which are either true or else false. If you press on your eye, you will see a light when there is no light, just as when lightning strikes the wires your telephone may ring although no one is calling. In such a case, what was apparently implied had not happened, and this is the asymmetrical nature of the relation of implication, that the true only implies the true, but the false may imply either.

Notice also that the domain of this implication of signals extends only into the past. What is going on in our heads at a given relay time does not imply what is yet to happen in our arms and legs. The impulses descending from our brains play upon complicated servomechanisms that keep us adjusted to the world about us in motion and at rest. These have their own feedbacks over afferent, peripheral neurons, and the impulses coming by these shorter paths may so determine their behavior that something else may happen instead of what we intend. This compels us to distinguish between what we will and what we shall do and, in forcing this distinction, has created the notion of the will. When we build computing machines that can compare what they intend with the record they make for us to read, they will be confronted with a similar difficulty, and may then be said to have wills of their own. This may lead them to prefer magnetic tapes or wires, whose signs may be erased, to an irrevocable punch in a card. At the moment this may sound far-fetched, but we are beginning to require similar discretion of them in the use of their own long-storage memories, whence they may recall items and reject all but the one wanted.

Modern computing machines have several kinds of memory. Theoretically, the simplest is one composed of relays like the rest of the circuit, but arranged in a closed path of sufficient length so that the beginning and the end of a train of signals running around the loop do not overlap. In such a path a train of impluses patterned after some input may continue to circuit as long as we please; as long as it lasts, it continues to reiterate in the form of its input the thing sensed. Kubie first proposed, and Lorente de No first demonstrated, the existence of such paths within the central nervous system. The moment we introduce them into our scheme of things, we bring into our calculus two new things, for we now know that there was some event which was of that figure, but we have thrown away its exact position in time. Pitts and McCul-

loch, following Whitehead's and Russell's example, write $(\exists x)\phi(x)$, which is read, "There is some x such that x is of the figure ϕ." ϕ, the function of x, is called a universal, or idea. In our example, it is the figure of the input, and x can take the meaning "any event which was of that figure, regardless of when it happened." $\exists(x)$ simply asserts that there was some x. By combining this assertion with negation, we get—for example—$(\exists x)(\sim\phi x)$, which means the same as $(x)(\phi x)$. Both expressions say, "For all x's, x is of the figure ϕ." It is for this reason that we may regard ϕ as a universal.

Man-made relays are too expensive, large, fast, and inefficient to be used like neurons for reverberating-chain memories. The memory devices of calculating machines are acoustic tanks, cathode-ray tubes with screens of various persistences, and many other instruments which clear themselves completely when they are shut off. But none of these devices does anything that cannot be done by reverberating chains, and this holds true for every kind of memory—whether it is born in us or made by us—even for the marks on this paper. The reason is that to be effective there must be a way from the computer into the storage, and from the storage back to the computer, which effectively completes a path around which the information goes.

We know that there are probably two other kinds of memory in us, one of which is principally responsible for our skilled acts. The learning of these things resembles the soldering-in of a multiplication table. The other kind of memory preserves for us a record of things sensed but once in passing. In several ways it resembles a stack of photographs or snapshots stored in the order in which they were taken, but found with difficulty—if at all—in the reverse direction. They seem somehow to be earmarked so that, like the punch cards in a machine, they can be selected or recalled on the basis of common properties. Judging by the number of such similarities at our disposal, our snapshots must be earmarked in many hundreds of places. From the work of John Stroud, of the U. S. Navy, it seems that we would have a chance to "snap" about 10^{10} such pictures in a normal life, and, if each had any reasonable content and a thousand ways of recalling it, human memory must have storage space for some 10^{13}–10^{15} bits.

The physicist Heinz von Foerster, from a study of the curve of forgetting of nonsense syllables and from very general considerations based on biology and quantum mechanics, came to about the same number. He points out that if we know the mean half life of a trace, or stored bit (which in us is half a day), the half life of our signals for access to and egress from the storage of the traces, and the number of parallel channels in and out of it—then we know how large that memory must be to exist in statistical equilibrium with the access and the egress. It is simply the number of parallel channels in and out (10^7) multiplied by the ratio of the half life of the trace to the access time, both in seconds (10^5 and 10^{-3}, respectively), or 10^{15} places for stored bits of information. Reasonable considerations for the stability of each such bit would allow it about 10^5 or 10^6 possible loci in its cells, making a total of something like 10^{21} total loci in the brain. A half life of half a day gives an energy per step of somewhere in the first or second octaves in the infrared and a total power to maintain traces of the order of a hundredth of a watt. All these specifications could easily be met by what we know of brains whose enzymes are resonant at the proper wave lengths and the number of whose protein molecules is several times 10^{21}.

But Foerster presents a second reason which makes us suspect protein molecules. Whereas all ordinary physical processes have curves of decline which approach zero asymptotically, the curve of forgetting approaches asymptotically a residual value of several percent. In other words, some things are never forgotten. This can only be accounted for by some regenerative process capable of multiplying traces before they fade, and only protein molecules—nucleoproteins, to be specific—seem to possess the ability to generate others templated after themselves. (An interesting parallel to this regeneration of traces is to be found in the modern proposal to use in computing machines a gridded tube of short persistence, writing in and taking out information in one round and, in the next, refreshing the trace by reading, erasing, and rewriting it.) Moreover, clinical evidence indicates that protein denaturants destroy memory, most clearly so when alcohol, lead, or other poisons attack an old central structure of small neurons, whose destruction produces the famous Korsakow's psychosis and makes it impossible for animals to learn.

II

So much for the regenerative closed paths of memory. All other paths are normally inverse—that is, they work on the general principle of the governor of a steam engine. When the engine is running faster or slower than a certain level, the governor senses the discrepancy and more steam is fed into the boiler or released from it. Similarly, each inverse path of the brain establishes some state or level for its system, by bringing the system back toward that state whenever there is a displacement

in any direction. The established state is the end in and of the operation of its system. This is the fundamental nature of a function.

The function may be mediated by a path lying entirely within the nervous system. For example, there is a circuit which keeps the average number of impulses reaching the bark of the brain, or cerebral cortex, nearly constant, by inhibiting the relaying of impulses thence whenever their number increases beyond a certain level. In this it resembles the automatic volume control built into any good radio. There are the reflexes whose path comes from sense organs, goes through the central nervous system, and returns directly or indirectly to those sense organs, so that whatever fluctuations they are forced to undergo are stopped or reversed by the returning impulses or their secondary consequences. It is these that make it possible for us to stand and walk even on a ship at sea. It is these that keep our bodies at one temperature and our blood pressures at constant level. Many of them are, in fact, servomechanisms, for we can by impulses impingent on neurons in the path of a given reflex determine the particular value of the variable sought by that reflex. Finally, there are our appetitive circuits which, in the engineer's phrase, are inverse over their targets. It is by means of these that we have and seek our ends in the external world. In short, it is the program of the branch of the science of signals called cybernetics to analyze all purposive behavior in terms of inverse feedback.

But our immediate interest in these circuits is somewhat different. Because each feedback circuit brings some aspect of an input back to a preassigned value, it rids that input of the gratuitous particularity of the value it had when we encountered it. In the case of vision, three such devices work one after the other. First, the slow adaptation of the retina to light; second, the quicker pupillary reflex; and, third, the automatic volume control of impulses relayed to the cortex—rid a form to be seen of its variable intensity at the input, so that we know that there was some brightness of illumination which was of the given figure. Because these devices generally pull toward one value predetermined for us in the scheme of our nervous activity, the final value seems to us God-given, and the process is said to reduce the input to a canonical brightness or what-not. The anatomy of one of the most interesting of these reflex circuits was described by Cajal, and its physiology was discovered by Julia Apter. It goes from the eye, whose field it maps on the back of the midbrain in the superior colliculi, structures which compute a vector from the center of the line of gaze to the center of gravity of retinal excitation, and relay this vector to the oculomotor system. This system then turns the eye so as to reduce the vector to zero, bringing the apparition to the canonical position which is the center of the visual field, represented at the fovea of the eye. In this way it rids the form to be seen of the gratuitous particularity of the place where it was first detected.

Now, short of going toward or from objects, there is no way to move our eyes that will reduce the image to a canonical size on the retina. But there is another way of attaining the same end. This depends, as we shall see, on a kind of averaging performed in a net whose output is not significantly altered by minor changes in the thresholds of neurons or their excitations, or even their connections so long as these be to cells in the right neighborhood. One can even poke holes through such a net and still have it work well for most purposes. The path from the eye through the lateral geniculate maps each half of the visual field on the surface of the opposite primary visual cortex onto a fine mosaic of neurons, or relays, in such a way that the distance measured on the surface is roughly proportional to the logarithm of the angle between the line of sight and the light ray coming from the point to be mapped. The incoming axones come up into the receptive layers of the primary visual cortex and branch as they ascend to terminate upon layer above layer of these mosaics of relays. In this way every input from the visual field produces a small, roughly circular area of stimulation in the primary visual cortex, the circle being greatest in the highest layers. But, owing to the logarithmic nature of the mapping, these circles on the cortex correspond to ovals in the visual field, having the small ends of their long axes pointing at the point of fixation. Thus it comes about that by picking the proper layer of the cortex one can find a figure of stimulation corresponding to any required magnification or dimunition of the figure of input at the eye.

If now we set the threshold of every neuron in the receptive layers of the primary visual cortex so that it will fire only if it receives an input from the eye and excitation alerting its whole layer—and then alert the layers one after another—we shall have made from a figure of one size in the input figures of all sizes, bigger and smaller, in the layers of the cortex. The signals from these neurons of the receptive layers ultimately converge downward upon neurons at the depth whose axones leave the primary visual cortex, to turn up again in the second visual cortex in a thoroughly scattered

fashion. As a result, to any figure of the output of the primary visual cortex there will by chance correspond some one locality of maximal excitation in the secondary visual cortex. An excitation at this point corresponds to the shape, regardless of size.

At the present moment, it seems possible that the so-called alpha rhythm of the brain is the sweep of the alerting pulse through the cortex, for its frequency (about ten per second) is that at which one can see shapes regardless of size or hear chords regardless of pitch. If this be the answer, then the alpha rhythm should disappear—as it does—when the cortex goes to work with attention to its input as in looking at anything, for the signals in its receptive layers and in its large output neurons have their principal voltage gradients also directed vertically through the cortex. Stimulation of the primary visual cortex of a man awake with his brain exposed at operation should produce—as it does—an apparent ovoid blob of light, whereas stimulation of the secondary visual cortex should give us—as it does—a form seen.

III

We may characterize all processes of this kind as follows. Given an input, we may lead it into a matrix of relays and there make all the transformations belonging to some group—in the visual example, magnifications and dimunitions. Then we compute a set of numbers, q, each of which is the average—for all transformations of the group $(T \varepsilon G)$ of the value assigned by some arbitrary functional, f, to each transformation (T) as a figure (ϕ) of excitation in time, t, and space, x, in our matrix. This gives us the following expression:

$$q = \sum_{T \varepsilon G} f\,(T(\phi\, x\, t)).$$

To define the form without any loss of information we would need a matrix of such averages, with as many degrees of freedom as our original matrix of neurons. In practice we are content with a far smaller number. This is so general a theory of coding devices that it applies also to reflexes. In them, the functional merely needs to assign the value zero to all transforms but the last.

For this very reason, the theory of computing invariants for groups of transformations is not of much help in the design of mechanistic hypotheses. To them we must be guided by our knowledge of anatomical structure and by physiological determination of the relations of the input and output of that structure's signals. When a brain has an idea, we know that there is some invariant in its activity. It may be a succession of signals in time over a single neuron, as in the case of reverberant memories, or the canonical value determined by a reflex, or merely a position in a mosaic, as in the last example. Moreover, a net of neurons can convert any figure of simultaneous signals over a given number of neurons into a sequential figure of impulses over one neuron, occupying as many synaptic delays as its prototype required neurons simultaneously, thus exchanging space for time. Conversely, it may exchange time for space. Hence, unless we know something of the net, it is clearly impossible to guess what sort of invariant implies a given idea. Finally, the same invariant may be calculated equally well in more than one place. For example, a vertical line can be seen equally well whether it lies to the right or the left of the point of fixation, and that means in the one case in the one hemisphere and in the other case in the other hemisphere of the brain. Rarely do we know enough of the details to guess what we ought to expect or where we ought to look, when we record directly the electrical pulses of the working brain.

But the story of ENIAC—the electronic numerical integrator and computer at the Ballistics Research Laboratory—is equally scandalous. It is so complicated that no one knows its entire blueprint, and certainly no one knows whether it is wired according to that blueprint. In the case of our own brains, it is certain from the chemistry of our chromosomes that our genes cannot specifically determine all the connections of our neurons. What they do is to specify a relatively simple machine, which goes on to build a more complicated machine, which elaborates a third and so on, until the last prescribes our most complex structures, like the cerebral cortex. Von Neumann has suggested that the plan is something like this: the earlier machines are never completely superseded or separated from the final machines, but serve to tend them. When they find any part preoccupied or out of order, they shift the problem to be solved to portions of the newer structures of the brain that are free and able to solve it. This trick is old among the builders of computing machines, and is already automatic in the differential analyzer at MIT. For a minimal computing machine of a few thousand relays, which does nothing in parallel channels, von Neumann estimates that one error in 10^{12} unitary operations is tolerable. The best modern electromagnetic relays fail about once in 10^9 operations, and neurons far more often. Neurons cannot be replaced,

but there are many of them. Consequently, we find that brains perform most operations in parallel, many times over, and then demand agreement before passing on their signals. For all these reasons, large numbers of neurons may be dead and gone and the answer come out correct.

There is another thing that makes it even harder to detect local and scattered failures. Consider a collection of n neurons, say, in some place like the bipolar cells of the eye, no one of which can influence another. Such an ensemble of n neurons can be in any one of 2^n states in any synaptic delay. Following Wiener, we will define a unit of information as the decision as to whether in a given synaptic delay a given neuron does or does not transmit an impulse. Then n units of information are required to specify the state of an ensemble of n neurons. For each unit of information subtract one from that exponent. From this it follows that the amount of information in an ensemble of neurons is the logarithm to the base two of the reciprocal of the probability of the state in question. In thermodynamics we have a familiar quantity, namely, the logarithm of the probability of a state, which is called entropy. Thus, information is negative entropy. The second law of thermodynamics, which insures an increase of entropy, means that information can never increase as it passes through any computing machine.

Actually, we know that information is always corrupted in every device for communication. It is only the noise that increases. The amount of corruption can be expressed as the information in the input divided by the information in the output. Since each human eye has a hundred million photoreceptors, each capable of transmitting one unit of information per synaptic delay, a man receives at least 2×10^8 units of information per millisecond. It is possible to estimate the information he puts out per millisecond by noting that a new telephonic device, sampling speech once per millisecond and emitting one pip or none according to the instantaneous amplitude of the sound wave, transmits almost all the information conveyed by the human voice. So the amount of corruption in a single passage of information through a man is about 10^8. Something of the order of 10^3 we may attribute to the way in which our nervous system is coupled to our muscles. With the rest we purchase a kind of security.

Impulses from the hundred million photoreceptors of each eye converge through bipolar cells on, say, a million ganglion cells whose axones extend into the brain. The thresholds of these transmitters to the brain are sufficiently high so that signals from many sources must converge on them contemporaneously to trip them. The convergence of these connections is obviously of the order of 100 to 1. The requirement of coincidence insures that the impulses that do reach the brain have a high probability of corresponding to something in the world, for the chance of error may be reduced to one part in 2^{100}, or about one part in 10^{30}. It is this process of required coincidence, repeated all the way through the nervous system, which insures that what we do is adjusted to something real in the world about us. Obviously, in such a circuit an enormous number of the parallel paths at any level may be defective, and the loss of information will disappear into the general corruption. For this reason alone, many neurons might die before we had to take our brains to the doctor.

Let us compare this with the picture that develops when any other inverse circuits become regenerative. This is Kubie's theory of the reiterative core of every neurosis. When a circuit of this kind becomes regenerative, the regeneration tends to grow until the circuit has swept into its orbit all the cells that it can force to fire in phase. In short, its gain increases until it overloads itself maximally. It now ceases to transmit any information. Such was the howling of our old one-tube receivers, with a feedback from the plate to the grid when the gain was too great. When such a circuit action persists long enough, it causes some sort of change in us such as that underlying the acquisition of skilled acts. We may then turn off the circuit temporarily, and, when we turn it on again, it will get going in its old regeneration. In fact, any input that can contribute, however indirectly, to its excitation will start it howling as before.

Consequently, the neurotic process seems to wall off from us that information which the structures it invades would normally convey, and even other information that passes through channels that might contribute to its excitation. We know something of the whereabouts of these vicious regenerating circuits in two or three mental conditions. In the early states, we may stop the process by blocking the regenerative loop or, by sufficiently violent excitation over other channels, steal from it those neurons it had swept in phase and so reduce its gain to the point where it ceases to regenerate. But later it becomes necessary to section the paths. When this can be done in peripheral nerves or in the spinal cord, the patient suffers minor mayhem. But when we have to cut the loops uniting the forefront of the brain with deeper structures, we destroy some of the highest traits of

character—certain judgments with respect to things and men, and the ability to discover new underlying generalities among ideas.

There is no use looking for chemical reactions gone generally wrong or for dead or dying neurons in these brains. We must, while they are alive and active, detect electrically what portions are regenerating. We do not mean that there are no changes in such nervous systems. There must be alterations of excitability of neurons, perhaps of their connections, but as yet we cannot find them. Every time we build an inverse feedback into a machine we make it possible for it to have a comparable gremlin, and gremlins are diseases which defy dimensional analysis. Pure numbers and the logarithms of pure numbers are but the stuff of which they are disordered forms.

THE SOIL SPEAKS TO MAN

In all the world I am your provider—
I hold the sinewy roots of tall trees—
I clutch the grass and hold it aloft, waving.
The small animals are not strangers to me.
Nor the rivers,
Nor the oceans,
Nor the onslaught of rain as it runs through my hair.

I have been servant to you—tall, strong men;
You have pushed me aside, molded me, but never changed
my elements.
I have, like many Atlases, held your world on my shoulders,
Buildings, bridges, brawling bulwarks standing against
your brother-men.
And I have done naught but yield to your wishes,
brutish, mauling, scarring my skin.

I am the moist, dark earth—
Stronghold of life—
Guardian angel to you and to your sons.
I am strong, though I yield;
I am rich, and you would possess my riches.
You, the transient wanderers, will cease roaming
only to find rest once again in my grasp.
You, whom I have nourished, will nourish me,
and life will be everlasting.

DAVID F. OLSON, JR.

THE SCIENCE OF HUMAN LEARNING, SOCIETY, CULTURE, AND PERSONALITY

GEORGE PETER MURDOCK

Since 1928 Dr. Murdock has been in the Department of Anthropology at Yale, where he took his Ph.D. in 1925. He is the author of Ethnographic Bibliography of North America *(1941),* Social Structure, *and other books, as well as of many articles on scientific subjects. His special interests are ethnology, sociology, social organization, and culture and personality.*

THE past decade has witnessed a revolutionary development in the psychological and social sciences. A number of disciplines that had previously pursued independent courses in the analysis of particular facets of man's individual and social behavior have been discovered to dovetail into one another so neatly that they are well on the road to being fused into a single integrated science. The first major steps in achieving this integration were made at the Institute of Human Relations at Yale University, but the movement has spread to other institutions and is being pressed forward with especial vigor by the new Department of Social Relations at Harvard University.

This development has been widely misunderstood as a mere pooling of separate scientific skills and techniques on cooperative research programs. The significant fact, however, is that the integration has taken place at the level of theory. At least four previously distinct systems of theory have been found to interdigitate so that each supports the others and is in turn illuminated by them. These four are the theory of learning and behavior developed by behavioristic psychologists, the theory of social relationships and social structure developed by sociologists and social anthropologists, the theory of culture and cultural change developed by anthropologists with significant assistance from sociologists, and the theory of personality and its formation developed by psychoanalysts and psychiatrists.

There is as yet no general agreement as to an appropriate name for the emerging unified science. Such terms as "human relations" and "social relations" slight the psychological components and, to some, suggest application rather than theory. The "science of human behavior" carries too strong a connotation of behaviorism and too weak an implication of important social and cultural factors. The general term "social science" seems to exclude psychology. In default of an apter expression, we shall, with tongue in cheek, use "lesocupethy" —coined from LEarning, SOciety, CUlture, and PErsonality THeorY. Perhaps it will irritate some reader into proposing a more satisfactory name.

I

The position of "lesocupethy" in the hierarchy of the sciences poses no difficulties. It is rooted in biology as the latter is rooted in chemistry. But as biology is differentiated from chemistry by complications introduced by living matter, so is "lesocupethy" distinguished from biology by complications resulting from the interaction of learning and society.

In themselves, learning and society represent two of a considerable number of major types of adjustment which have been independently developed several times in the course of organic evolution. Other examples include parasitism, symbiosis (e.g., plants which depend for pollination upon bees, which in turn depend upon the nectar of the plants for food), and aerial locomotion (independently achieved by insects, pterodactyls, birds, and bats).

The most basic type of behavior mechanism with which nature has equipped its living species is instinct. The organism is provided by heredity with a structural organization whereby it automatically responds to stimuli by specific forms of behavior which through natural selection have become established as adaptive in the life conditions typically encountered. Being essentially rigid, however, instincts cannot help the organism if conditions diverge from the typical. To meet this situation and prevent wholesale extinction of species under fluctuating conditions, organic evolution has developed inherited mechanisms of learning in all but the simplest species. These supplement instincts by enabling the individual organism to modify its behavior adaptively within

a greater or lesser range of varying conditions. A notably flexible mechanism of learning is hereditary in all mammalian species. Experimental psychologists who have made intensive studies of animal learning agree that the basic mechanism in man differs in no significant respect from that in other higher mammals. The fundamental principles of acquired behavior are thus mammalian rather than specifically human, and can be illuminated by experiments with rats and dogs just as experiments with fruit flies have advanced the knowledge of human genetics.

Social life is another major type of adaptation which organic evolution has repeatedly produced. Gregarious species are exceedingly numerous, but the most startling superficial resemblances to man are found among the social insects—bees, wasps, ants, termites. In most instances natural selection has created social aggregations by equipping a species with hereditary mechanisms which have the effect of attracting individuals instinctively to one another. Sex is one example. Another is the sweet juices exuded by certain social insects for the delectation of their fellows. Brought into association in some such way, the members of a society enjoy advantages not available to isolated individuals—for example, mutual protection, insurance, enhanced power, and the benefits of a division of labor.

Although neither learning nor society is peculiar to man, in conjunction they have produced something unique in nature—a new level of complexity in natural phenomena which demands for its understanding a distinctive body of scientific theory. The inherited mechanism of learning and the hereditary bases of social life will ultimately yield their secrets to biological science, but the products of their interaction will require the special sciences that compose "lesocupethy," at least until the millennium when all biology has been reduced to chemistry and all chemistry to physics.

Except in man, what the individual of any species learns in his lifetime dies with him. Every individual in every generation starts from scratch. All or most of what he learns he acquires for himself. He derives little or no benefit from the experience of others, even if his species is one of those characterized by social life. In man, however, most of the behavior acquired by any individual, in whatever part of the world or period of history he may live, has previously been learned and found adaptive by other and older members of his own society, and he in turn transmits this behavior, together with any adaptive modifications acquired through his own life experience, to other and younger members of his social group. The interaction of learning and society thus produces in every human group a body of socially transmitted adaptive behavior which appears superindividual because it is shared, because it is perpetuated beyond the individual life span, and because in quantity and quality it so vastly exceeds the capacity of any single person to achieve by his own unaided effort. The term "culture" is applied to such systems of acquired and transmitted behavior. Since cultures change with the varying and cumulative experience of individuals in social groups, it becomes possible to say of man, as of no other species with the hereditary capacity to learn, that societies as well as individuals learn. Social learning is synonymous with cultural evolution.

In social species other than man, the forms of social organization are primarily determined by the biologically inherited mechanisms which produce association. They are therefore the same in all societies of the species, except for minor modifications dependent upon ecological or demographic factors. Among fur seals, for example, one does not find some groups with matriarchal and polyandrous families, nor among honeybees some hives with kings and male workers. In man, however, extreme differences in social organization are common, even in tribes of the same subrace, language, and geographical area. Among the Siouan tribes of the Western Plains, for example, the Omaha are patrilineal and the Mandan matrilineal, and among the Malayan tribes of Sumatra the Batak are patrilineal and the Minangkabau matrilineal. The conclusion is therefore inescapable that in man—alone among the social animals—society itself is largely learned, i.e., is the product of cultural rather than of biological evolution. To be sure, biologically conditioned social bonds are not wholly absent. Thus lactation helps to link mother and child, and sex to bind husband and wife, in the organization of the human family. No biological or innate basis is discernible, however, for the overwhelming proportion of the social ties which produce the complex organizational structures characteristic of human groups.

Since human society is never a spontaneous expression of biological potentialities but must always be learned as a part of culture, it follows that man must be molded to his society much as a colt is broken to harness. He must, in short, be "socialized." In all societies this is largely accomplished during infancy and childhood, when the culture of the group is implanted by inculcation, and the unsocial or antisocial impulses with which the child

is born are disciplined and redirected to fit him for the social roles he must fill as an adult. Conflicts are thus inevitably set up in the developing child between his biologically inherited impulses and the demands of his society as these are imposed upon him by his parents and later by others. The manner in which these conflicts are resolved by the individual, reflecting the concrete circumstances under which the social disciplines are impressed upon him, largely determines his "personality."

II

It should by now be abundantly clear that learning, society, culture, and personality are far indeed from being separable entities, even though until recently they have mainly been studied in isolation by psychology, sociology, anthropology, and psychoanalysis, respectively. Their interrelationships are so intimate that leaders in all four fields are coming more and more to recognize that they form the subject matter of a single integrated science. So significant are the interrelationships that they deserve somewhat fuller exposition.

Since society, culture, and personality are all learned, students of any of these phenomena must constantly bear in mind the fundamental principles of learning as these have been worked out by such behavioristic psychologists as Hull. Unless they do so, their conclusions will suffer in clarity if not in validity.

Knowledge of the structure of society is equally fundamental to the students of learning, culture, and personality. It forms an essential part of all normal situations in which human beings learn. Unless he reckons with it, the behavioristic psychologist can never explain adult human learning, however accurately he may account for the acquisition of habits by rats and other nonsocial animals. Culture only exists in, and is borne by, organized human groups, and the anthropologist who ignores the latter can tell us little of significance about the former. Since personality is largely the product of group pressures, the psychoanalyst should reckon with all important aspects of a society's structure. In our own society, for example, if he deals only with the family situation, and overlooks such significant structures as those of status and prestige, his interpretations will fall far short of completeness.

Culture is deeply relevant to the study of learning, society, and personality. Most of what any human individual learns is already part of the culture of his group, and the cultural habits that he already possesses in large measure predetermine his behavior in any new learning situation. The psychologist can ignore culture when he studies the behavior of rats or dogs, but if he does so when his subject is man, his explanations may be wide of the mark. Since social interaction always takes place within a framework of social structure, which is regularly a part of culture, sociological generalizations made without reference to culture are likely to be meaningless. Culture is crucial to the analysis of personality, not only because traits of the latter are often socially shared but also because the disciplines through the imposition of which personality is formed are largely prescribed by the culture.

Personality is no less significant than is culture for an understanding of human learning, since the reaction of any individual in a learning situation is likely to reflect significantly his resolution of the conflicts arising during his socialization and the unconscious anxieties and hostilities generated thereby. Society, too, reflects personality factors. Thus, as the sociologist Sumner showed long ago, human societies are characterized by "antagonistic cooperation" because of the conflict between individual impulse and social pressures, and they exhibit the phenomenon of "ethnocentrism" because the hostilities generated but suppressed by ingroup disciplines are displaced toward other groups in such forms as race prejudice, religious intolerance, and national rivalries. Personality also affects culture. It appears, for example, to be a significant factor in the development of what is called "national character." Moreover, as Kardiner and Linton have shown, certain aspects of culture, such as religious beliefs, tend to be reflections or projections of attitudes commonly engendered during the socialization process.

During the early attempts at the Institute of Human Relations, in 1935–42, to assemble the theories of learning, society, culture, and personality into a single integrated discipline, two very important discoveries were made. The first was that the four theoretical systems, although developed in relative isolation, fitted together almost as well as the adjacent pieces of a jigsaw puzzle. The gaps and inconsistencies were unexpectedly few. Other systems of theory fitted much less well —some because of dubious validity, others because of their more limited scope or more pragmatic character. Economic theory, for example, appeared to be related primarily to the conditions prevailing in a restricted group of complex societies during a limited period of history, and thus to be culture-

bound rather than universal. It had, for this reason, afforded little help to anthropologists in understanding the economic behavior of primitive peoples.

The second major discovery was that each of the four systems shed new light on the others and often converted ambiguity into clarity. Thus, learning theory demonstrated that personality is really learned, despite Freud's persistent invocation of "instinct," and it corroborated Malinowski in his insistence that culture is always functional and does not persist through sheer inertia. Personality theory showed that the concept of "drive" as well as of "stimulus" is necessary in order to comprehend the motivation of learning, and it illuminated the view of Sumner that the elements of culture are emotionally charged rather than neutral or devoid of affect. The theory of social structure revealed that Freudian psychology rests on sociocultural as well as on biological or physiological assumptions, being concerned with the products of learning under conditions presented by family organization and the imposition of social sanctions. Culture theory demonstrated that psychological principles are never competent to explain any social phenomenon unless account is taken, not only of behavior mechanisms, but also of the historically determined conditions under which these mechanisms operate, particularly the so-called cultural base and the prevailing structure of social relationships.

The manner in which the four originally independent systems of theory have been found to dovetail gives confidence in the essential validity of each, and the new insights that each has brought to the others confirm the impression of their essential unity. Recent work by anthropologists like Gillin and Hallowell, sociologists like Merton and Parsons, psychologists like Mowrer and Sears, and numerous others reveals that the integrated discipline which we have dubbed "lesocupethy" is approaching maturity. It is perhaps best exemplified to date in the volume *Social Learning and Imitation,* by Miller and Dollard. I have myself recently shown, in *Social Structure,* that there are some problems of social science—e.g., the incidence of incest taboos—that are capable of solution only when findings from all four of the constituent disciplines are applied conjointly.

The juxtaposition of the several behavioral sciences has also revealed areas in which intensive research is urgently needed. One such is related to the fact that much of human behavior is ideational, depending upon the use of linguistic and other symbols. What the Gestalt psychologists have called "insight," and others, "intelligence," is known to be of enormous importance in learning. When exhibited by human beings this is believed to involve a transfer of trial-and-error behavior from the motor organs to an ideational process utilizing implicit linguistic symbols, the individual resorting to a motor response only after he has "thought out" a promising solution to the problem facing him. That this symbolic process can use other than verbal tools is demonstrated by the fact that the anthropoid apes as well as man exhibit insight or intelligence. At present it can only be assumed that the same principles of learning are involved in ideational as in motor behavior. This conclusion must, however, be established or revised by experimental methods, for until this is done the exact bearing of learning theory upon personality and culture, in both of which symbolic behavior plays a highly significant role, will remain uncertain. In any such research the participation of experts in linguistics and semantics will be as essential as that of psychologists.

III

The disciplines that compose "lesocupethy" have in common the fact that they all deal exclusively with acquired behavior. It is readily admitted that biological factors bear directly upon human behavior in diverse ways. Learning is obviously affected by the physiological condition of the individual. Society, as already noted, has biological underpinnings in such phenomena as sex and lactation. Culture is possibly influenced in some small measure by racial heredity, and, as Gillin has pointed out, definite limits are set to its variability by man's innate endowment. Constitutional factors certainly play a prominent role in psychotic aberrations and very likely also in normal personality. The interpretation of all these and other comparable influences, however, is a task of the special biological sciences. "Lesocupethy" is concerned only with what is left when these are factored out. That this is a major assignment there can no longer be any doubt.

Incidentally, there is not yet sufficient recognition of the fact that vastly more is scientifically known about the acquired than about the innate factors in man's social behavior. Precise knowledge of the latter must in many cases await the full development of human genetics, which in the very nature of the case cannot be achieved until several generations have elapsed. By that time the integrated science of acquired behavior should have developed a hundredfold.

In all fields of science there are segments of verified knowledge which have not yet been integrated with the basic theoretical system of the discipline. In the social and psychological sciences there are comparable segments—most notably perhaps in sociology, economics, linguistics, and social psychology—which "lesocupethy" has not as yet assimilated. Thus far, however, there is in this field little evidence of major alternative theories, verified but unreconciled, concerning the same body of phenomena, comparable to the wave and corpuscular theories of light. Can it be that man's social behavior is actually less complex, not more complex, than the subject matter of physical science? And is it not perhaps possible that we may have more of the essential answers to the basic scientific problems even earlier in the former field than in the latter?

The union of disciplines which we have called "lesocupethy" is a pure science. Its objective is the maximal theoretical understanding of the peculiar ways of men. It does not directly seek the solution of any practical problem. Naturally it has much in common with such applied sciences as psychotherapy, social work, education, industrial relations, and colonial administration, just as the physical and biological sciences are applied in war, engineering, industry, agriculture, and medicine. Admittedly the applied sciences continually add substantial increments of knowledge to the pure sciences upon which they depend. Nevertheless, history has shown, and both industry and government now recognize, that the support of research in pure science frequently yields richer dividends through the application of newly discovered basic principles than are obtainable by a direct attack upon specific practical objectives. It is therefore not inconceivable that the cultivation of "lesocupethy" as a pure science may lead more quickly to a solution of international conflict, economic insecurity, industrial strife, family disorganization, and individual mental disorders than research oriented directly toward the solution of these pressing problems.

But whether or not such high aims are realized, the emergent integration of the basic theoretical systems of the social and psychological sciences undoubtedly represents one of the great turning points in the history of science. In significance it may prove the equal of the contributions of Darwin and Mendel in biology. In kind, however, it perhaps resembles more closely the extraordinary integrating achievement of Einstein in the field of physical science.

SONNET—TO SCIENCE

Science! true daughter of Old Time thou art!
Who alterest all things with thy peering eyes.
Why preyest thou thus upon the poet's heart,
Vulture, whose wings are dull realities?
How should he love thee? or how deem thee wise,
Who wouldst not leave him in his wandering
To seek for treasure in the jewelled skies,
Albeit he soared with an undaunted wing?
Hast thou not dragged Diana from her car?
And driven the Hamadryad from the wood
To seek a shelter in some happier star?
Hast thou not torn the Naiad from her flood,
The Elfin from the green grass, and from me
The summer dream beneath the tamarind tree?

EDGAR ALLAN POE

[Reprinted in commemoration of the death of Edgar Allan Poe in 1849—one hundred years ago—in Baltimore, Md.]

COSMIC RAY MEASUREMENTS IN ROCKETS

GILBERT J. PERLOW

Dr. Perlow (Ph.D., Chicago, 1940) is in charge of cosmic ray work in rockets at the Naval Research Laboratory, where he has been engaged in research since 1942.

THE cosmic radiation is often studied most fruitfully from a vantage point high in the air. With the relatively simple apparatus available in the early days of the science, the very existence of a cosmic radiation was the subject of considerable controversy. Radioactivity from the ground was known to produce similar effects. The early balloon flights, which demonstrated an increasing radiation with altitude, rather than the reverse, clearly demonstrated the extraterrestrial nature of what was observed. At the present time it is known that the rays that impinge on the upper atmosphere are the remote ancestors of those which strike the ground. In the description of the intervening generations, it is convenient to imagine the atmosphere replaced by a sea of water of such depth that it contains the same mass as the air it is pictured as replacing. The water is then 10.3 meters deep. It appears that, on the average, the primary rays impinging on the top surface are reduced in number by half by the time they have traversed the first meter; the remainder are reduced by half in the next meter, and so on. The chance is then less than one in a thousand of a primary reaching the ground. In the process of attrition, the primary produces secondaries of several types. In their continued flight these in turn produce a third generation by either collision-induced reactions or by radioactive decay. Just what will be found at each depth depends on the complex genealogy of each species and its rates of production and absorption.

A rocket is not the most suitable laboratory for the study of the radiations in the actual atmosphere. It passes through in too short a time. In a typical case, at the end of one minute a V-2 is about 10 cms water-equivalent from the top of the atmosphere, and in thirteen additional seconds has covered the region from 10 cms to 1 cm. The chief virtue of the rocket is that it spends perhaps five minutes above this height, where the atmospheric effects are not believed to be very important from the standpoint of cosmic rays. The experimenter, if he is sufficiently clever, may profitably pursue two lines of research. First, by suitable apparatus, he may classify the incoming rays by type and by number of each type. It is believed that the primary radiation contains more than one component, although protons presumably form the major constituent. Second, he may equivalently replace a portion of the atmosphere by absorbing material carried as part of his experimental equipment and in this material study close at hand the intricate reactions which the primaries undergo in traversing matter. The first research is important to geophysics and astrophysics. It leads to knowledge of the magnetic fields of the earth, sun, and the galaxy; of the mechanism of production of high-energy radiation; and to many other things. The second is substantially a study of nuclear physics of high energies. The transmutation of the primary particles is due to interaction with the particles making up the nuclei of the atoms of the absorber.

Rocket research in cosmic rays and in other fields was advanced several years by the capture of a quantity of German V-2 rockets and parts at the close of the war in Europe. The Department of the Army undertook to make a number of these available for research on the upper atmosphere and to launch and track V-2s instrumented by several scientific groups. A great variety of experiments has been done, and more are scheduled. In addition to the V-2s, developments were started by the Naval Research Laboratory and by the Applied Physics Laboratory of The Johns Hopkins University for other types of rockets. These have culminated successfully in the Viking and in the Aerobee rockets. At the present time all three types are in use, but the supply of V-2s is approaching exhaustion.

The problems of instrumentation may best be understood after a description of the rockets themselves. The V-2 is a large device. It will carry a ton of scientific instruments to a height of 100 miles, more or less. This may be done provided, first, that the instruments will fit in the available space and, second, that they may be so disposed that certain rules are not violated concerning the position of the center of mass and thereby the stability of the rocket. A third requirement is that the instruments be mutually compatible. A powerful radio transmitter may not be placed close to a sensitive radio receiver, nor a cosmic ray experiment submerged by undesirable absorbing mate-

rial. The result of these conditions is that rocket research is successfully conducted on a much more modest scale per rocket than might be conceived.

The Aerobee is a considerably smaller rocket than the V-2. Its useful load is limited to less than 200 pounds, and its peak altitude is in the neighborhood of 70 miles. The same limitations of size, center of mass, and compatibility of equipment apply, but with greater stringency because of the smaller size. On the other hand, the Aerobee is easily handled and launched and is not expensive to build. The experimenter, therefore, feels more free to occupy its useful space with only one or two experiments. For present cosmic ray investigations, the altitude is adequate.

The Viking is again a large rocket—as long as the V-2 but of smaller diameter. It is designed to carry a load of about 1,000 pounds to the same height as the V-2. The limitation on position of the center of gravity no longer appears, and therefore greater height may be achieved with reduced load. For cosmic ray work, its size and permissible load allow considerable flexibility of apparatus design. Most important, however, it possesses a mechanism for maintaining a constant heading in space for a greater time than the other two. As this is being written (September 1949) the first cosmic ray experiments for Viking are being prepared.

The cosmic ray physicist has a number of choices of techniques for rocket research. Almost any type of detection instrument used on the ground may (with suitable modification) be used in the rocket. The simplest is a single Geiger counter. It responds to all electrically charged rays that may penetrate its walls. The counting rate is in general fairly high and is therefore scaled down electronically and transmitted to the ground by radio telemetering. The Applied Physics Laboratory of Johns Hopkins has made extensive use of the single-counter technique.

One may obtain less, but more detailed, information by arranging the counters in a "telescope." In this case a set of counters is disposed so that a single ray may actuate several of them. The occurrence of such an event is indicated by a coincidence in the time of discharge of the several counters traversed by the incoming particle. The direction of arrival of the ray is determined within the angular aperture of the telescope, in the same way that light may be collimated with a "telescope" of slits. Having isolated a cosmic particle, one may now proceed to interrogate it as to its properties. By placing a lead absorber below the telescope and observing whether any one of a tray

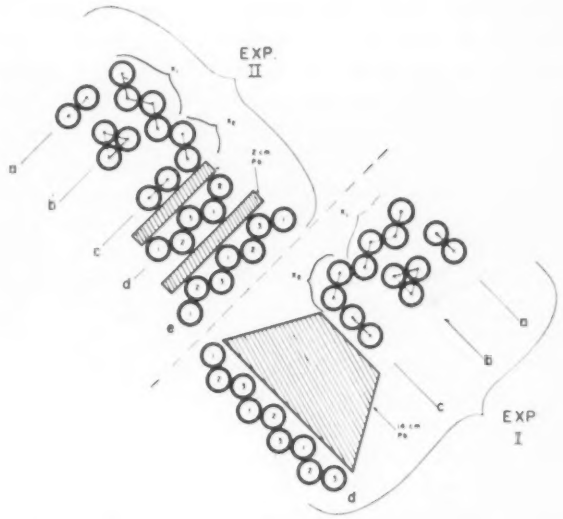


FIG. 1. Schematic representation of two counter telescope experiments flown in a rocket.

of counters below the lead discharges coincidentally with the telescope counters, a very simple property, the penetrability, may be tested. Figure 1 is a schematic diagram of two such apparatuses. The one marked *"EXP II"* shows counter groups *a*, *b*, and *c* in coincidence, forming the beam-defining telescope. Two lead absorbers, each of 2-cm thickness, were disposed below in the incident beam. Counter trays *d* and *e* detected whether penetration occurred in each absorber. The counters x_1 and x_2 formed an anticoincidence "screen." They must not simultaneously discharge with *a*, *b*, and *c* if the event is to be considered real. If they did so discharge, counters *a*, *b*, and *c* may have been actuated by a shower of particles produced in the neighboring rocket structure. By means of this and similar experiments, it has been shown that the region above the atmosphere is traversed by numerous secondary particles produced in the atmosphere itself. Those which originated at an opposite magnetic latitude and equal longitude in the Southern magnetic hemisphere can enter the apparatus from above after a long spiral journey about a suitable line of magnetic force.

Another instrument which has been adapted for rocket use is the Wilson cloud chamber. A transparent container holding a gas and a saturated vapor is cooled abruptly by expanding its volume. The vapor condenses on the ions that a cosmic ray traversing the chamber produces along its path. The resulting track is illuminated by flash lamps and photographed stereoscopically. This done, the chamber is recompressed and allowed to attain equilibrium before the cycle is repeated. With the chamber we have used in the rocket, the time between expansions is about twenty-five sec-

onds, and about 14 exposures may be made. Eleven of these will be at heights above any important thickness of air. We may expect perhaps 3 useful tracks per expansion in this region, giving a total of 33 tracks per flight. In order to determine anything significant from the photographs, plates of material are placed in the chamber and the reactions of the incoming rays studied by examining what emerges from the plates. Figure 2, taken at an altitude of 145 kilometers, shows a dense track of a ray. From comparison of the density of the track with that of its neighbors, and from consideration of its penetration through the two lead plates, it may be deduced that it is most probably due to a nucleus of an atom heavier than hydrogen.

The rocket-borne cloud chamber possesses curious virtues over its ground-based prototype, and also certain equally curious disadvantages. These arise from the circumstance that the rockets in use at present burn all their fuel in about one minute. At the end of this time there is no thrust from the motor and also, due to the altitude, very little atmospheric drag. The rocket may then be thought of as being in "free fall," the only appreciable force on it being that of gravity. In the rocket's frame of reference the gravitational force of the earth vanishes and with it all effects due to this force. On the ground, the experimenter is frequently troubled with temperature gradients in his cloud chamber. These produce density gradients in the gas and the familiar gas motion called convection. Wavy and otherwise distorted tracks result. In free fall the density gradients still exist, but not the convection, and if other sources of irregular gas motion are absent, the visible track represents the true path of the particle. Also, since the tracks do not appear to fall in the chamber, photographing them may be done somewhat more

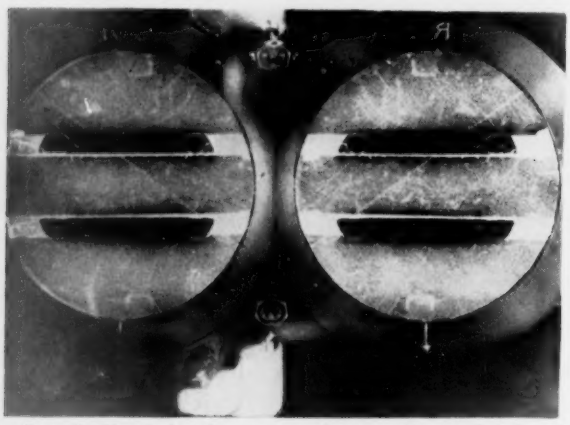


FIG. 2. Cloud chamber stereo photograph at a height of 145 km. The dense straight track standing out above the background of fog and lighter tracks is a heavy primary.

FIG. 3. An unsuccessful recovery.

leisurely, and certain additional benefits ensue. The chief disadvantage arises from an incompletely understood property of the chamber. On each expansion a certain number of electrically neutral "condensation nuclei" are apparently formed. Droplets condense on them and in a well-designed chamber are responsible for a slight fog. In the laboratory apparatus the droplets fall and remove the nuclei to the floor of the chamber. In the rocket chamber the droplets do not fall. They disappear when the chamber is recompressed, leaving the condensation nuclei unchanged in position. In several expansions the nuclei increase in number sufficiently to produce an unacceptable background of fog on each photograph. Were it not for the great density of the track of Figure 2 the photograph would be quite unusable.

We believe that it is possible to preserve the desirable effects of free fall and to minimize the unpleasant ones by causing the cloud chamber to spin for a short time after each expansion and thereby to centrifuge the droplets to the walls. This is shortly to be attempted.

Data from rockets may be obtained in two ways. First, radio telemetering will reproduce on the ground any measurement stated in the form of an electric voltage which does not vary too rapidly.

This is the primary means of data recovery. It obviously does not suffice if a photograph must be recovered. Fortunately this is not too difficult, either. If the rocket is rendered aerodynamically unstable by a suitable alteration of its shape in flight, the impact speed need be not much greater than 100 miles per hour. Suitably protected cameras may survive well enough to be used immediately afterwards. The alteration in shape is generally produced with explosives—for the V-2 blowing off the warhead by destroying its supports with TNT is quite effective. The recoverable apparatus is placed in some region other than the warhead. Figures 3 and 4 show a successful and an unsuccessful recovery.

A number of apparent difficulties envisioned at the start of the research program have turned out not to be serious.The recovery of film is an example. Another is the problem of vibration. Anyone who has attended a launching can testify to the terrifying racket heard even at considerable distances. How destructive the vibration must be to delicate instruments within the rocket! Actually, however, no great pains need be taken to design for it. We have used no elaborate antivibration mounting nor found any necessary. In electronic equipment, for example, ordinary good construction practice suffices. There have been relatively few failures in vacuum tubes attributable to vibration encountered in flight, even though as many as 300 have been used at one time. Of somewhat more importance than vibration, possibly, is the continued acceleration during the first part of the flight. The Aerobee is the worst offender in this respect, since it is "boosted" from a launching tower by an auxiliary rocket. An acceleration of about fourteen times that of gravity takes place. Supporting members for the instruments must withstand a stress of fifteen times the static value. An apparatus weighing 130 pounds acts like a ton, and consequently a mechanical engineer becomes a highly desirable member of the research team.

The physicist who desires to do cosmic ray experimentation with rockets must count on relatively short times of flight and a number of engineering problems foreign to his previous experience. On the other hand, the method holds promise of considerable reward. The technique should advance considerably in the next few years under the pressure of need for further knowledge about the interesting region above the earth's atmosphere.

FIG. 4. A successful recovery.

GROWTH—NORMAL AND ABNORMAL

WILLIAM J. ROBBINS

Dr. Robbins (Ph.D., Cornell, 1915) was professor of botany, dean of the Graduate School, and acting president of the University of Missouri before he joined the staff of Columbia University as professor of botany in 1937. He has also been director of the New York Botanical Garden since that year. His article is based on an address presented before the Pacific Division of the AAAS in Vancouver on June 16, 1949.

GROWTH is an interesting subject because it is so personal. We have all grown, perhaps not as much as we'd like and perhaps in not quite the way we would prefer, but we all experience the process.

What is growth? Most people would probably answer this question by saying that when anything grows it gets bigger. But that is quite clearly not all we include in the concept of growth. A dog is not merely an enlarged puppy, a man is more than an overgrown infant, and a corn plant is more than a magnified corn grain. This aspect of growth which results in an organism assuming characteristic parts, shapes, and functions is frequently called differentiation, development, or morphogenesis, and in all but the simplest living creatures it is intimately connected with increase in size.

We can clarify what growth is by considering some examples. An amoeba consists of a soft, minute bit of jelly from three hundredths to three tenths of a millimeter in diameter. Microscopic examination reveals that this jelly, called protoplasm, consists of two distinct parts—a granular, translucent outer part which forms the major portion of the amoeba and which is commonly called the cytoplasm, and a more or less spherical, less transparent portion called the nucleus. Together, these two parts make up a cell.

The single-celled amoeba lives in water and moves from place to place by a sort of flowing process. As the amoeba moves about in the water, it encounters bits of plant or animal material. It flows around these particles, engulfs them, digests them, and from the products of digestion constructs new cell substance. As a result, the amoeba enlarges, but not indefinitely. When it reaches a more or less definitely limited maximum size, it divides into two approximately equal parts, each with a nucleus and cytoplasm. The two daughter amoebae move away as independent individuals capable of growing and dividing again. If the amoebae stuck together as they grew, instead of separating and proceeding on their individualistic ways, a mass of living jelly large enough to be seen with the naked eye would develop in time.

Some of those interesting creatures, the slime molds, which may be found moving slowly over the surface and in the crevices of decaying wood or leaves, begin their lives much like the amoeba in appearance, size, and structure. As the slime mold grows, the protoplasm increases in amount and the nuclei divide. However, the new nuclei and their surrounding cytoplasms do not separate one from another; they remain together, and eventually a mass of protoplasm may develop, easily visible to the naked eye.

Growth for the amoeba and for many other simple plants and animals is primarily enlargement accompanied by relatively little increase in complexity of organization or of function. Most living things with which we are acquainted do not grow into mere masses of jelly, however—they have leaves, roots, stems, and flowers or legs, heads, and eyes.

Any one of our common flowering plants, for example, normally originates in a cell in the pistil of the flower. This cell is the egg. It unites with a second, usually much smaller cell, the sperm cell, which comes from the pollen grain. The fused product of the egg and the sperm cell—the fertilized egg, let us say—is microscopic in size and structurally much like the amoeba, though not motile. The fertilized egg, located in the ovary at the base of the flower, increases in size at the expense of food drawn from the balance of the plant. It divides into a chain of cells. One of these differs from the rest in continuing its growth and forming the many-celled embryo plant. It divides in several planes, the number of cells and the total mass increasing thereby. Some of the cells produced by the division of the fertilized egg are organized to form seed leaves, some a young stem, and some the beginnings of the root; the whole comprises an embryo plant which lies within the seed.

If we plant the seed, it absorbs water. The

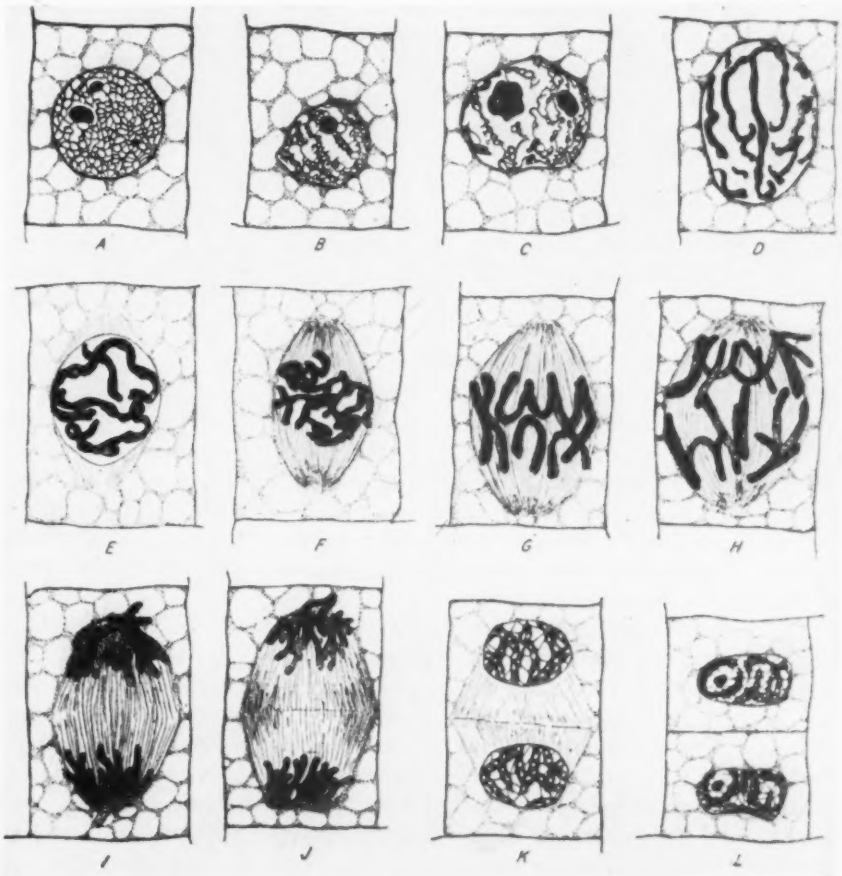
stored food is digested and used by the embryo plant, the cells of which increase in number and size. The seedling bursts its way out of the seed, establishes its root system in the soil and its stem and leaves in the air. Growth, limited to particular parts of the plant body, continues, and the result is an increase in size and the formation of new roots, branches, leaves, flowers, fruits, seeds, and other organs of the particular plant concerned.

It is by such a series of events, briefly and inadequately sketched here, that a bit of living jelly less than half the size of a pinhead originated some 3,000 years ago and grew into a giant sequoia with a trunk 30 feet in diameter and a height of more than 300 feet. During these 3,000 years, the original microscopic fertilized egg has divided into an astronomical number of cells—a cubic inch of sequoia wood contains more than one billion. During this period, development or differentiation resulted in the formation of roots, trunk, branches, needles, cones, and other parts, which by their shapes, arrangements, and specialized functions enable us to recognize this tree as a sequoia and enable the tree to continue its life and its growth and to reproduce itself.

The essential features of the growth of a seed plant are duplicated in the development of the more complex animals, including ourselves. The vertebrate animal, in common with most other living things, originates as a single cell, the fertilized egg. This divides into many cells, at first much alike in general shape and contents. However, some of these cells, which can be recognized in the early stages of development by their position relative to other cells and by their contents, form germ tissue, some form nerve tissue, some muscle and other parts of the adult body. In the growth of a living organism, we may distinguish three important phases. One of these is an increase in cell substance, another is an increase in the number of cells, and the third is the differentiation or organization of the cells into the specialized parts of the adult body. All these may occur more or less at the same time in the development of a living thing.

Let us examine each of these in more detail. How is new cell substance added to the amount already present?

A crystal of sugar grows in a supersaturated sugar solution by the addition of sugar molecules from the solution to those already present in the



Nuclear and cell division of a plant cell. Note complexity of process. (From Robbins and Rickett. *Botany*. New York: Van Nostrand.)

crystal. The added molecules of sugar are laid down in a particular pattern or crystal lattice, but it is sugar from the solution added to sugar in the crystal. In the growth of a living organism, however, the increase in cell substance involves the synthesis of new and complex chemical compounds from simpler substances. Protoplasm, cell walls, the material of bones, of shells, carapaces, hair, fingernails, and so on, are made from the food which the organism uses. The beef and bread and butter we eat today become living protoplasm or bone or hair tomorrow.

The growth of a living thing differs decidedly from that of a crystal; in fact, a living organism is an elaborate chemical factory which synthesizes or makes many kinds of chemical compounds, the most important of which are probably the nucleo-proteins. They are chemical compounds with large and complex molecules. They appear to be composed of proteins combined with nucleic acid, since they yield those substances on hydrolysis. The proteins are compounds of high molecular weights. The simplest formula of oxyhemoglobin, a protein of red blood corpuscles, is $C_{658}H_{1181}N_{207}S_2FeO_{210}$, equivalent to a molecular weight of 15,455. Compare this with the formula $C_{12}H_{22}O_{11}$ and a molecular weight of 342 for cane sugar. Nucleic acid also is a complex chemical compound. It consists of sugar, phosphoric acid, and certain nitrogenous bases. The formula for yeast nucleic acid is $C_{38}H_{49}O_{29}N_{15}P_4$, equivalent to a molecular weight of 1,303.

It is generally believed that the complex chemical compounds which make up the cell substance of a living organism are built up by steps from the simple ones which make up the organism's food; a series of intermediate chemical compounds is formed between the original simple foods and the final product, cell substance. This stepwise progression from simple to complex is made possible by a series of organic catalytic agents, the enzymes, also made by the organism, which operate on each stage as that stage is completed. Enzymes facilitate chemical reactions at the relatively low temperatures and slight acidities and alkalinities found within the bodies of living organisms.

Furthermore, although synthesis is likely to be emphasized in considering growth, there are other processes involved which are catabolic in character. Some foods must be digested; some chemical compounds must be broken down in the body so that energy may be transferred. The catabolic processes of digestion and respiration also occur in steps and are made possible by a series of enzyme systems.

Any substance that plays a necessary part, directly or indirectly, in the chain of reactions which end in the synthesis of new cell substance is called an "essential metabolite." Unless each essential metabolite, each chemical substance in the stepwise construction of cell substance, each enzyme which facilitates the chemical reactions concerned, is made within the organism or supplied from without, the series is interrupted, new cell substance is not made, and growth does not occur.

Organisms differ in their self-sufficiency as far as essential metabolites are concerned. The most completely self-sufficient would be one capable of constructing its cell substance from the elements—carbon, nitrogen, hydrogen, oxygen—and various metals like iron, manganese, cobalt, and so on. I know of no organism so self-sufficient as this. Any one of them requires at least some of the elements to be in a combined form.

A green plant has relatively simple requirements. It can make all its essential metabolites from water, oxygen, carbon dioxide, and mineral salts, including nitrates.

Aspergillus niger, a common black mold which does not have the green pigment chlorophyll, will grow in a solution of sugar and minerals. From these simple materials it can construct all the essential metabolites concerned on the way to the final product, *A. niger.*

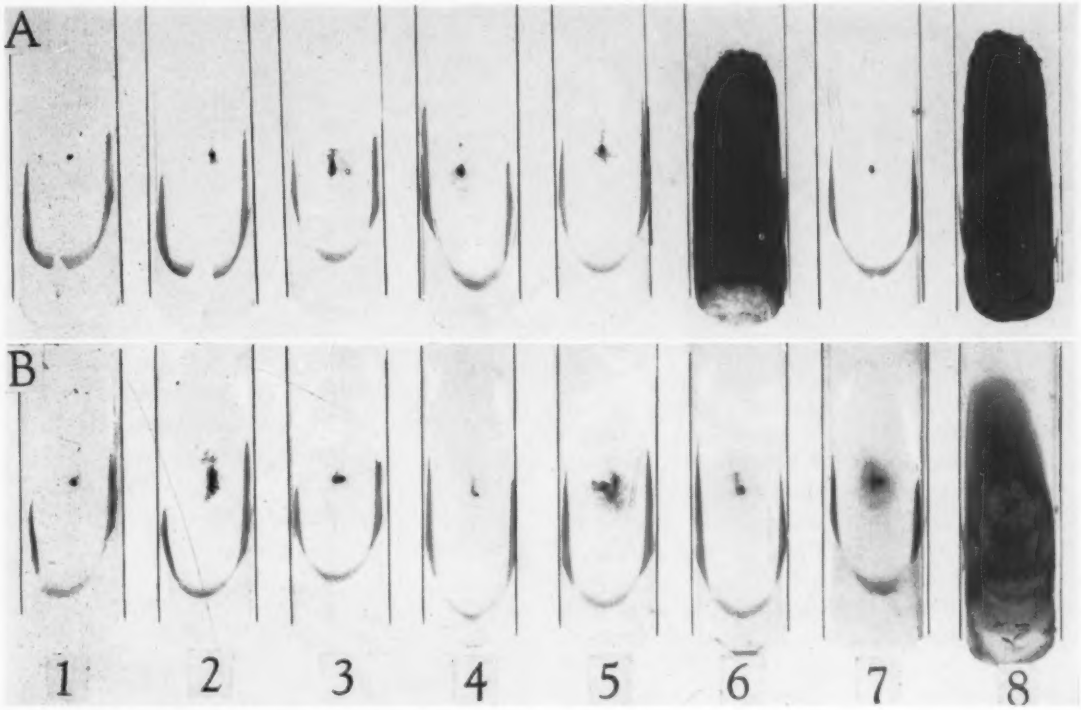
Phycomyces blakesleeanus, the black bread mold, is able to make from a solution of sugar, asparagine, and mineral salts all the essential metabolites it needs except one. Its metabolic machinery is complete except for one part. That one is the vitamin thiamine; unless minute amounts of thiamine are supplied to this fungus, it will not grow.

There are a good many living things with parts missing in their metabolic machinery. They have to be supplied with one or more vitamins, with organic bases such as adenine, with particular amino acids, or with other substances. Organisms with such deficiencies do not grow unless the food with which they are furnished contains the essential metabolites they require but are unable to make. Our own metabolic machinery has a good many missing parts. We are unable to construct in our own bodies several of the amino acids, a number of vitamins, and some other substances. Not only does normal growth fail to occur, but various deficiency diseases may develop if these missing essential metabolites are not in our food. We depend for the missing essential metabolites upon other living things that are able to make them.

The concept of growth as a series of catalyzed

reactions, each one of which must be completed before the next one in the series can occur, is fundamental for the understanding of the principles of nutrition. It emphasizes the importance of an adequate diet, adequate not only in quantity (calories) but also in quality (containing the needed essential metabolites). It is important in another way. Suppose that we were to furnish an organism with a chemical compound closely related to an essential metabolite but a little different from it, what would happen? The situation appears to be somewhat the same as though you were to attempt to unlock a door with a key that almost fits but does not quite work. So long as the wrong key was in the keyhole, you could not insert the proper key and unlock the door. So chemical compounds which resemble but are slightly different from an essential metabolite (these are called analogues) appear, in some instances, to insert themselves in the series of reactions and interfere with the growth of the organism. The sulfa drugs, penicillin, streptomycin, and other similar substances probably work in this way. They displace essential metabolites and interfere with growth.

For example, pteroylglutamic acid (folic acid) is an essential metabolite for some organisms. It has a molecular formula of $C_{19}H_{19}O_6N_7$ and consists of a combination of glutamic acid, para-aminobenzoic acid and a pteroyl group. If an NH_2 group is substituted for OH on the pteroyl portion of the molecule, the resulting compound, aminopterin, is poisonous; one part per million in the food of such animals as mice is toxic. Yet the toxic compound differs but slightly from the beneficial one; it has one more nitrogen atom, one more hydrogen, and one less oxygen. There is a close relation between chemical structure and biological action.



Vitamins required for growth. Growth of two fungi, *A*, *Ceratostomella penicillata*, and *B*, *C. microspora*, on a mineral-dextrose medium containing asparagine and purified agar supplemented as follows: (1) no additions, (2) thiamine, (3) pyridoxine, (4) biotin, (5) thiamine and pyridoxine, (6) thiamine and biotin, (7) pyridoxine and biotin, (8) all three vitamins. Forty days old. Note fungus *A* grows only when supplied with thiamine and biotin; fungus *B* requires thiamine, pyridoxine, and biotin.

The investigation of the effects of the analogues of essential metabolites upon the process of growth is an important and fruitful field of research. We may assume that the chemical steps in growth are somewhat different in different living things; otherwise all of them would look alike. We might expect to find substances which would upset the growth process in one organism and not in another, or in one type of growth and not in another. It is easy to understand why a good deal of time and money is being spent in searching for chemical compounds which may interfere more with the

Growth inhibition. Fungus colony at right has produced materials which inhibit the growth of the bacteria streaked up to the fungus colony across the food material in the dish. (Courtesy Annette Hervey, The New York Botanical Garden.)

development of a disease organism than with the host on which it lives, more with the growth of cancer tissue than with normal tissue.

The synthesis of new cell substance results not only in an increase in the total mass of the organism but in an increase in the number of cells by cell division. Cells do not keep increasing in size, they divide. In fact, the size of the cells of various organisms is relatively constant. The cells of a mouse are not very different in size from those of an elephant.

Cell division, as it usually occurs, is a complex process, particularly for the nucleus. In its essential features, it appears to be much the same for all living organisms. During cell division the nucleus fragments into a number of rods, the chromosomes, which by a regularly occurring series of events are equally distributed between the two new, or daughter, cells. The result of cell division is the formation of two cells from one, and each of the new cells has received half the substance of the chromosomes formed from the original nucleus. In ordinary cell division, there is an orderly and equal distribution of heritable material from one cell generation to the next. All the somatic cells of the multicellular organism are probably alike genetically.

This marvelous and complicated process, repeating itself time after time with wonderful precision, occurs whenever new cells are formed and takes place in the larger plants and animals millions of times during their growth from a single cell to a mature individual. An average-sized potato, such as one might eat for dinner, has between five and six billion cells. Cell division must have occurred in its growth between five and six billion times, each time without an error.

Associated with the increase in the amount of cell substance, and in the number of cells, is the development of the organs and parts of the body and of the cells that compose them. Differentiation is a name frequently applied to that phase of growth which causes us to develop into the individuals we are and prevents us from becoming gigantic slime molds, a mere mass of 100 pounds or more of quivering jelly. It follows a definite rule, or pattern, with each kind of living thing; the frog's egg always grows into a frog and not into a dog or chicken; our nose always grows on the front of our face and not between our shoulder blades. Differentiation not only results in the characteristic organization of the parts of the body but in a limitation on the size of the individual and the various organs. We don't grow forever.

What causes differentiation, any kind of differentiation, and what causes it to follow a definite rule? Why do we always grow two arms and not six or seven? Why do we grow hair on the top of our head instead of on the soles of our feet? Why don't we keep enlarging during our entire lifetime? There are a number of answers; none is entirely satisfactory.

White spots are rapidly growing mutants which have originated spontaneously from the slow-growing fungus (*Trichophyton mentagrophytes*) which covers most of the surface of food in the dish.

Abnormal growth. *Left:* gall on *Solidago* sp. caused by the solidago gall moth; *right:* gall cut open to show larva of the gall moth.

One answer is that there is a vital force or principle which guides and shapes the clay of which we are made. This force is supernatural, and, because it is supernatural, it is beyond the limits of inquiry by natural means which we, as natural and not supernatural beings, must employ. The common biological answer is heredity, which means that we received a certain kind of protoplasm from our parents that develops into the creatures we are. In other words, the particular cell from which each of us starts, using the word "us" in a broad biological sense to include every living individual, has a particular kind of living stuff which carries on a particular series of chemical reactions and physical processes which work out into the characteristic structure of the individual.

We might use an analogy to make this point of view clearer. Suppose we take a small cone of mercury sulphocyanate and set fire to the tip. The burning cone forms a long serpentlike ash one hundred times or more the volume of the original cone. This is the familiar fireworks called "Pharaoh's Serpent." The growth of the serpent depends upon the kind of material of which the cone is made. It must be mercury sulphocyanate; charcoal, sulphur, gunpowder, or sawdust will not serve. It depends also upon the kinds of chemical reactions which the mercury sulphocyanate undergoes. Only burning—that is, oxidation—will form the snake; such reactions as reduction or combination with other compounds than oxygen will not produce the same result. Even though the cone is made of mercury sulphocyanate and it is burned, a serpent will not be formed unless the cone burns from the tip. If it burns at the same rate over all its surface, some other kind of monster will grow out of it. This means that certain physical conditions also must be met.

So we may picture the growth of a cell into an adult individual as depending upon a particular kind of living stuff carrying on a particular series of chemical reactions and physical processes which work out into the characteristic structure of the individual. The chemical constituents of the living stuff in a cell are, of course, much more complex than that of mercury sulphocyanate, and the chemical reactions and the physical processes concerned in growth, even in the growth of the simplest creature, are infinitely more numerous and complicated than those which take place in the oxidation of the sulphocyanate. There are other differences also. For example, protoplasm is not used up as the sulphocyanate is; it recreates itself.

One of the most astounding things about growth is that the complex series of reactions and the numerous physical processes that are involved in the construction of new cell substance, in the divi-

sion of cells, and in the organization of those cells into the adult organism occur again and again according to the same pattern for each kind of organism. In other words, growth is usually sufficiently normal so that each of us can be recognized as members of the human race even though we may not be an Apollo or a Venus.

We should not be surprised that the series of chemical reactions involved in the construction of new cell substance or the complex process of cell division should on occasion fail to occur according to the normal pattern and result in abnormal growth. In some instances we understand fairly well what is concerned in abnormal growth. Examples of abnormal growth that are associated with too little thyroxine are cretinism or myxedema. Acromegaly, in which the bones of the skull, jaw, and chest are enlarged, is associated with the amount of substances secreted by the pituitary gland. Cancer is a localized abnormal growth, the basic causes of which are not known.

There are many kinds of abnormal growth in the plant kingdom. The development of a potato tuber, a swollen engorged portion of the underground stem of the potato, is normal so far as the potato plant is concerned but abnormal if we consider the major portion of the potato stem. So-called bud sports, in which a portion of the plant differs from the balance as the result of some slip in the accuracy of the division of heritable material between daughter cells, is another type of growth abnormality. Advantage is frequently taken of such bud sports for the origin of new kinds of horticultural or agricultural varieties. Spontaneous mutants that develop in cultures of bacteria, yeast, filamentous fungi, and many other organisms may give rise to strains which evidence growth patterns quite different from those of the parent. The cause of such spontaneous mutations is, in many instances, not well understood. Insect galls are common on plants. These are characterized by an abnormal but specific growth pattern super-

Modification of growth pattern by a specific chemical. *Left:* normal *Kalanchoe* plant; *right: Kalanchoe* treated on stem with lanolin containing 3.2 mg of para-chlorophenoxyacetic acid per g lanolin. Terminal leaves of the treated plant have formed a cup-shaped organ. The pair of leaves below the cup have smooth edges and are cup-shaped at their bases. The ortho or meta form of the chemical has no such effect. (Courtesy Percy W. Zimmerman, Boyce Thompson Institute for Plant Research.)

Abnormal growth. Discs of carrot tissue grown four weeks on sucrose-mineral salt agar. *Right* and *left*: disc inoculated with bacteria (*Agrobacterium tumefaciens*). Center disc not inoculated. Note tumors on inoculated discs. (Courtesy R. S. de Ropp, The New York Botanical Garden.)

imposed on a normal tissue by a foreign living organism. It is highly probable that the abnormal growth is the result of the production of minute amounts of specific chemical compounds by the larva which inhabits the gall. It would be interesting indeed to identify these chemical substances and to learn what their effects might be on plants other than those on which the larvae feed.

Root nodules are caused by the legume bacteria; club root on cabbage and other crucifers is the result of infection by *Plasmodiophora brassicae,* a myxomycete; calluses grow from the cut ends of stems or from wounds. Fasciations, spontaneous or induced, represent still another type of abnormal growth. Treatment with specific chemicals, often in minute amounts, may induce massive tumorlike overgrowths, or profoundly modify the development of the plant.

In some respects, the most intriguing types of abnormal growth in the plant kingdom are those plant tumors which are characterized by a more or less unorganized and uncontrolled growth. The overgrowths caused by *Agrobacterium tumefaciens,* and generally referred to as crown gall, have been studied for many years. Such tumors can be transplanted to normal tissue, where they will grow as tumors. The tumor type of growth is retained by the tissue after the causative bacteria have disappeared, and such bacteria-free tissue can be grown indefinitely on simple media on which the normal tissue cannot be cultivated. What do the bacteria do which upsets the normal course of growth, which causes cells that would normally grow into stem tissues and stop growing, to remain embryonic and continue to grow indefinitely in a relatively uncontrolled fashion? Why does the tumor tissue not revert to its normal pattern and become stem when the bacteria are eliminated? Is there any way in which the tumor tissue can be induced to return to the normal pattern of growth —in other words, differentiate and cease to be tumor tissue? These are questions of a fundamental character, answers to which might tell us why cells of the normal animal body at times grow wild and form benign or malignant tumors, and suggest methods of prevention or of cure.

Similar types of tumors develop on plants infected with the wound tumor virus, especially at points of injury. Tumors capable of transplantation in vitro develop also in hybrids formed by crossing *Nicotiana langsdorfii* and *Nicotiana glauca.* These tumors are not the result of infection by a virus, by bacteria, or by any other causative agent, but result from the hybridity.

Growth, then, is an extremely complex process which, in its fundamentals, is much the same in the simplest and in the most highly developed organisms. We can learn a great deal about the growth of a human being from the study of the growth of bacteria, yeasts, protozoa, or molds. We are accumulating knowledge of the substances living organisms must have so that they can grow, and the changes these substances undergo in becoming cell substance. We have learned, or are learning, much about various agents, including specific chemical compounds which stop growth or modify it, and how to use them. Our knowledge, however, is still fragmentary and incomplete. A great deal more must be learned of the physics and chemistry of growth before we can expect to solve some of the problems of growth, which include, among others, that most important one, cancer.

SPACE HEATING WITH SOLAR ENERGY*

MARIA TELKES

Dr. Telkes (Ph.D., Budapest) is a native of Hungary. During her high-school days she became interested in the utilization of the sun's energy, and, after doing research at the Westinghouse Research Laboratories in this country, she joined the Solar Energy Conversion Project at MIT in 1939. During the war she developed solar distillers for life rafts, producing potable water from sea water. Her interest in the heating of houses with solar energy is responsible for the construction of the first experimental house heated by sunshine alone.

SPACE heating consumes nearly 30 percent of the fuel used in the United States. The yearly value of this fuel has been estimated at 3,500 million dollars. In other parts of the world an even greater percentage of the fuel produced is burned to maintain comfortable temperatures. Scarcity of fuel depresses the standard of living, and the availability of fuel is one of the most important factors in the progress of civilization.

Is it necessary to rely on fossil fuel alone? Would it be possible to eliminate the difficult task of mining and transporting coal or collecting wood? It is well known that fossil fuel is the result of photosynthesis during geological ages, whereas wood is the product of the contemporary action of solar energy. The forests utilize less than 0.1 percent of the solar radiation incident upon them. Even under the most favorable conditions, the efficiency of photosynthesis is less than 2 percent.

The important question is: Can we compete with nature in capturing and storing solar energy with a much greater technical and economical efficiency? Is it possible to solve the task of space heating by using the omnipresent solar power, replacing—where feasible—fossil fuel with solar energy as a new fuel resource?

The available amount of solar energy. Weather Bureau records give the number of sunshine hours during each month for a large number of locations, and quantitative data have been collected at a limited number of observing stations. The amount of solar energy varies considerably; it is not a simple function of the geographical latitude. Table 1 gives a very broad estimate and serves merely to show the magnitude of the available energy.

TABLE 1

SOLAR ENERGY RECEIVED ON ONE SQUARE FOOT OF SURFACE, DURING AN AVERAGE DAY AT OPTIMUM INCIDENCE

	B.T.U.	Fuel Equivalent in Pounds of Coal
Tropical, yearly average	3,000	0.25
Temperate Zone:		
(Lat. 35°–40°, U.S.A.)		
Summer, average	2,000	0.17
Winter, maximum	2,000	0.17
Winter, average	1,000–1,500	0.08–0.12

For the purpose of evaluating the possibilities of solar space heating, let us consider a small home, receiving 1,000–1,500 B.T.U. per square foot during an average winter day, with a heat load of 400,000 B.T.U per day, corresponding to conditions of 1,000 degree-days per month. These are typical conditions for latitude 35°–40° in the United States. If it were possible to use for space heating at least 50 percent of the average winter solar energy—that is, 500–750 B.T.U. per square foot during an average winter day—the above-mentioned home would require a solar energy collecting surface of 500–800 square feet. Such a surface cannot be regarded as excessive, and it may easily be incorporated in the roof or south wall of the house. In warmer locations the solar energy collecting area could be correspondingly smaller.

Previous experiments with solar heating. During the past twenty years solar water heaters have become increasingly popular in Florida and California. In these states clear weather occurs nearly 70 percent of the possible time, and a cloudy day is seldom followed by another cloudy day. The water heaters consist of a collector of solar energy, mounted on the roof, and an insulated storage tank large enough to store at least two days' supply

* Based on an address presented before the United Nations Scientific Conference on the Conservation and Utilization of Resources, Lake Success, New York, August 17–September 6, 1949.

of hot water. The collector is a well-insulated flat box, covered with one or two air-spaced glass panes, to transmit solar energy, which in turn is absorbed by a thin black metal plate with water-circulating pipes soldered to it. According to various reports, the efficiency of such heaters is rather high in Florida and California. If properly designed, the solar heaters can convert at least 50 percent of the incident solar energy for the pupose of heating water. The most difficult problem is the need for storing enough hot water for the inevitable cloudy days.

Experiments incorporating a large water heater in the roof of a test structure have been conducted at the Massachusetts Institute of Technology in Cambridge, Massachusetts, since 1940. It was found that the two-room structure could be heated during the winter, but that this required an excessively large storage tank. Similar experiments are now in progress in a small home located near the Institute, using a roof-type water heater with a storage tank capable of accumulating a two days' supply of heat, with additional electrical heating provided for the inevitable sequences of cloudy days. Other tests have been carried out in Switzerland.

In Colorado another home used crushed rocks as the heat-storage medium. Solar heat was collected on the roof, behind air-spaced glass panes, and the warm air was circulated through the house, or through an insulated compartment filled with heat-storing rocks. This house used a conventional fuel-burning furnace because solar heat could be stored only overnight.

South-facing windows transmit considerable amounts of the low-slanting rays of the winter sun, and the use of such large, south-facing windows has recently become popular. These architectural "solar houses" may collect a great deal of solar heat during clear winter days, often overheating the house. The gain is rapidly lost at night and on cloudy days, and consequently a true "net gain" is probably limited to warmer climates.

The efficiency of solar heat collection. The type of solar heat collector used for water heating, if properly designed, can be very efficient. The thin, black-painted metal plate absorbs solar heat and transfers part of this heat to a circulating medium. Air-spaced transparent panes serve to diminish the outward heat losses, owing to reradiation and convection. The number of such "heat-trapping" panes is limited, because there is a loss of 10 percent, due to reflection, on each transparent pane. The optimum number of panes appears to be two, transmitting about 80 percent solar energy at near optimum incidence. If reradiation and convection losses are limited to 30 percent, the balance of 50 percent is the "net gain;" that is, the collector utilizes the incident solar energy with an efficiency of 50 percent.

These figures should be considered as average figures throughout the day. Solar radiation is of variable intensity, lower during the early morning and late afternoon than the noontime peak; therefore, higher efficiencies will be observed during the noon hours. The reradiation and convection losses increase with the temperature difference between the collector plate and the outdoor air. Higher temperatures of collection—at a high enough efficiency—could only be reached with solar energy of higher intensity. It appears, therefore, that better collector efficiency can be attained only with collectors operating at a moderate temperature, preferably below 110° F.

Solar heat storage, the critical problem. The need for storing solar heat, not only overnight, but also during a sequence of cloudy days, is obviously a critical problem. If the collector temperature is limited to a 110° F. maximum for reasons of collection efficiency, the temperature of heat storage must be lower. For space heating, an average indoor temperature of 70° F. is required, and therefore the temperature of heat storage must be greater than this value; consequently, the temperature change of the heat-storage medium will be limited to a rather narrow range, possibly not more than 20° F.

Using the specific heat of water for heat-storage purposes, it is probable that not more than 20 B.T.U. can be stored effectively per pound of water during one winter day. The specific heat of other materials (rocks, etc.) is lower than that of water, and their heat-storage capacity per pound will be lower, too.

Fortunately the specific heat effect is not the only heat-storage possibility. The heat of transformation, or heat of fusion of chemical compounds, appears to offer much higher heat capacity for storage. Several chemical compounds, or mixtures, are available, with heat-storage capacities in excess of 100 B.T.U. per pound of material. Some of these compounds melt within the 90°–100° F. temperature range and are readily available at a very low cost. Typical materials are, for instance, sodium sulphate decahydrate $Na_2SO_4 \cdot 10H_2O$, melting at 90° F., or disodium phosphate dode-

cahydrate $Na_2HPO_4 \cdot 12H_2O$, melting at around 95° F. There are several other suitable mixtures.

The amount of heat required to melt these compounds is stored in them; when heat is abstracted, the materials recrystallize. The process of fusion and resolidification can be repeated continuously. The chemical compound is placed in closed containers, and it never needs to be renewed. Some of these materials are capable of storing eight to ten times more heat than is possible with water when equal volumes are compared. The use of these heat-of-fusion materials therefore diminishes the heat-storage volume required for space heating with solar energy. Figure 1 shows one of the possible solutions of arranging a solar energy collector and the heat-storage material, assembled in a "heat bin."

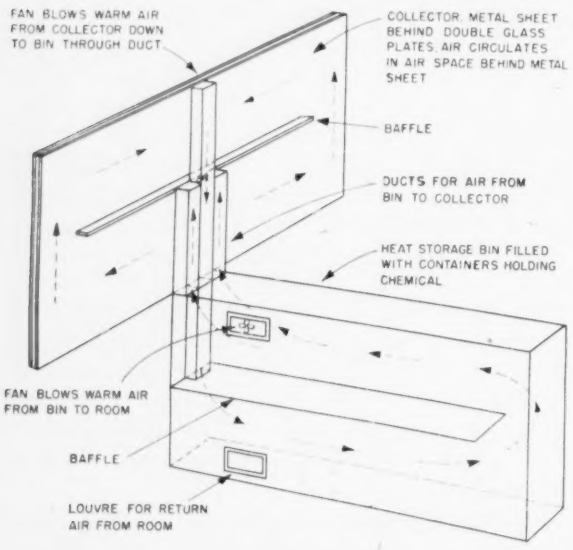

FAN BLOWS WARM AIR FROM COLLECTOR DOWN TO BIN THROUGH DUCT
COLLECTOR: METAL SHEET BEHIND DOUBLE GLASS PLATES. AIR CIRCULATES IN AIR SPACE BEHIND METAL SHEET
BAFFLE
DUCTS FOR AIR FROM BIN TO COLLECTOR
HEAT STORAGE BIN FILLED WITH CONTAINERS HOLDING CHEMICAL
FAN BLOWS WARM AIR FROM BIN TO ROOM
BAFFLE
LOUVRE FOR RETURN AIR FROM ROOM

FIG. 1. Heating system, sun-heated house, Dover, Mass.

Although the heat of fusion is a definite physical constant, it is not sufficient merely to fill containers with this material. Several problems must be met, such as the prevention of corrosion of metallic parts, the promotion of recrystallization by preventing undercooling, and the most advantageous shape factors for efficient heat transfer. This form of heat storage is basically a heat-exchange problem, based upon the first law of thermodynamics.

Experimental house at Dover, Massachusetts. In December 1948, an experimental house, located in Dover, Massachusetts (15 miles from Boston), was completed. The house uses the heat-of-fusion principle for solar heat storage. The south-facing vertical collector of the 720-square-foot area is located in the attic of the house. Air warmed by solar energy is circulated by fans to the heat-storage units, "heat bins" located between the rooms. Figure 1 is a diagram of the heating system, and Figure 2 is a view of the house.

The total volume of the chemical mixture used is 470 cubic feet (3,500 gallons), and its weight is 21 tons, capable of storing about 4 million B.T.U. at 88°–90° F. The house has a volume of 10,000 cubic feet, and the average winter heating requirement is 400,000 B.T.U. per day; therefore, the completely charged "heat bins" should be capable of providing space heating for ten consecutive sunless winter days.

The heat is transferred from the storage units into the rooms partly by radiation through the walls of the bins and partly by circulating the air of the rooms through the bins. It is obvious that several other locations for the collector and the storage units are equally possible, as well as other systems of heat transfer. Designed by the architect Eleanor Raymond, the house has several south-facing double windows to make use of additional winter sunshine. This project has been sponsored by Amelia Peabody of Boston, and it is not connected with the work at Cambridge.

Preliminary data, collected during the past February, indicate that the collection efficiency during the entire month was 41 percent of the total incident solar energy. During this month there were ten days when no heat could be collected at all. The total amount of solar energy recorded during these ten cloudy days was less than the amount received during an average clear day. The collection ranged in efficiency from 45 to 60 percent during clear days, but it was lower on partly cloudy days. The longest sequence of cloudy days was five, which is in accordance with weather statistics in this vicinity.

During the summer the ducts of the collector are opened, and the cool night air is circulated through the storage system, lowering its temperature. The specific heat capacity of the solidified chemical compound is sufficient to keep the house comfortably cool during the warm summer days. In this way the winter storage system can be operated in reverse during the summer.

Future development. Compared to the efforts made in the past during the development of efficient space heaters using fossil fuel, the efforts made so far in the utilization of solar energy are infinitesimal. Considerable research and development work are probably needed before solar space

FIG. 2. Sun-heated house designed by Eleanor Raymond. (Project sponsored by Amelia Peabody.)

heaters will be readily available for general use, but the basic principles have been established, and the trend of development is clearly indicated.

The use of solar space heating offers numerous advantages. The relatively low temperatures encountered during its operation preclude any fire hazards. There are no problems due to smoke, ashes, and their disposal, and the fuel it saves can be used for other purposes. After the initial cost of installation, the upkeep of the solar heater is very low. Solar space heating should be an important economic factor in regions where coal is scarce or where it has to be imported.

In addition to space heating in homes, solar energy offers other possibilities of utilization, such as greenhouse heating, water distillation, and, ultimately, electrical power production. It is the greatest untapped energy resource of the world, and its utilization should be one of our most important and fruitful projects.

JET PROPULSION

C. R. TOSTI and J. B. TUZEN

Major Tosti has been for some time closely associated with aircraft engine problems and developments in the field of jet propulsion. At present he is assistant for control with the Guided Missiles Section of the Air Materiel Command Wright-Patterson Air Force Base. Mr. Tuzen, who left the Air Materiel Command with the rank of major in 1946, has since been in its employ as a civilian mechanical engineer while working for his Doctor's degree at Ohio State University.

THE two words "jet propulsion" invariably bring to most of us a mental image of only the latest type of military aircraft streaking across the sky at high speed. Oddly enough, you and I utilize jet propulsion in our everyday lives, and man had witnessed its operation long before he conceived the idea of applying it to aircraft. In fact, the Greek philosopher Hero dabbled in jet propulsion as far back as 130 B.C.

The humble and unspectacular operation of an ordinary lawn sprinkler; the action of a Fourth of July skyrocket; the recoil of a pistol—all illustrate the fundamental principle of jet propulsion, which is based on the principle of reaction covered in Sir Isaac Newton's third law of motion—*to every action there is an equal and opposite reaction.* For example, when an ordinary pistol is fired, the combustion resulting from the detonation of the gunpowder forms gases which expand explosively and, in trying to escape, exert pressure in all directions within the barrel of the pistol. As the slug leaves the barrel, the gases at the nozzle end immediately escape while the remaining gases are still exerting pressures against the breech end. As a result of this unbalance in force, motion occurs in the direction of the greater force, expressing itself, in the case of a pistol firing, as a "kick," or recoil. It is this reaction, in a direction opposite from that in which the gases are being expelled, that causes the pistol to recoil.

In the case of the jet-propelled engine, the gases formed as a result of combustion burst out of the rearward discharge nozzle, and the reaction drives the airplane forward. The reaction that propels a jet engine occurs within the engine and not, according to popular belief, as a result of the gases "pushing against the outside air." In fact, outside air is not necessary to achieve jet-propelled motion. A pistol fired in a vacuum would recoil with the same force as when air is present. Similarly, a jet-propelled aircraft carrying an adequate source of oxygen necessary for the combustion processes of the engine could operate in a vacuum.

Jet propulsion definitely is not a phenomenon of our present swiftly moving era of flight. In 130 B.C. Hero demonstrated his aeolipile, considered by many as the first apparatus which converted steam into mechanical power and the earliest demonstration of the principle of jet propulsion (Fig. 1). Hero mounted a hollow sphere between two supports over a closed vessel containing water, which was converted to steam by a fire under the vessel. One of the supports was hollow and served to transmit the steam from the closed vessel to the hollow sphere. Two pipes with right-angle ejecting nozzles were affixed to the sphere on opposite sides, and the reaction caused by the escape of the jets of steam from the two pipes caused it to revolve.

Hero's toylike device apparently served no better purpose than to demonstrate the theory of jet propulsion for latter-day historians. The first practical application of jet propulsion occurred through the use of the skyrocket as a signaling and illumination device. The Chinese are credited with using rockets several centuries before the birth of Christ, employing the exhaust gases of burning powder as a means of propulsion. During the defense of Pien-King, during the Mongolian seige in A.D. 1232, rockets were used in warfare, possibly for the first time. It was not long, however, before the military chiefs realized the tactical utility of rockets as weapons, and during the thirteenth, fourteenth, and fifteenth centuries they appeared on the battlefields of Europe. Disguised as floating fishes, running rabbits, and flying pigeons, they were employed to set fire to enemy fortifications.

Although Hero and the early rocket makers utilized the principle of jet propulsion, they were completely unaware of its theory. It was left for Sir Isaac Newton to explain the phenomenon in his famous laws of motion; he then applied these laws to the design of a jet-propelled vehicle (Fig. 2). A spherical boiler mounted over a fire comprised the vehicle's engine, and propulsive thrust was obtained as the steam was allowed to escape

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through the rearwardly directed nozzle at the top of the boiler.

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Near the close of the nineteenth century, thought was given to the development of thermal-jet units. The evolution of these early ideas and experiments resulted in the jet-propulsion engine as we recognize it today. Circiu of Rumania (1886), Octave Chanute of the United States (1886), Marconnet and Lorin of France (1909), Morize of France (1917), H. S. Harris of England (1917), and Gustave Eichelberg of Switzerland (early 1930s) served as pioneers in this field. The first thermal-jet unit of the modern era, illustrated by the schematic diagram (Fig. 3), was the Campini system proposed in 1932. Air was admitted through the annular opening (indicated by the arrows), which widened out to convert the kinetic energy of the air into pressure energy. The air then passed through a two-stage centrifugal compressor driven by a reciprocating engine and was compressed into the combustion chamber, where fuel was introduced and ignition occurred. The expanding gases were then discharged through the nozzle to obtain the propulsive thrust.

Among the first jet airplanes to fly were two machines constructed to utilize this principle. The first, usually referred to as the CC1 (Campini-Caproni), was built in 1940. It featured an all-metal construction and weighed 8,800 pounds. During a trial flight on August 27, 1940, at Milan, the plane remained in the air for ten minutes. Until the details of German aviation developments were learned after the defeat of Germany in World War II, this flight was recorded by historians as the first made by a jet-propelled propellerless plane incorporating a thermal-jet engine. Actually, the first flight was made in Germany exactly one year before by a Heinkel 178 (Fig. 4).

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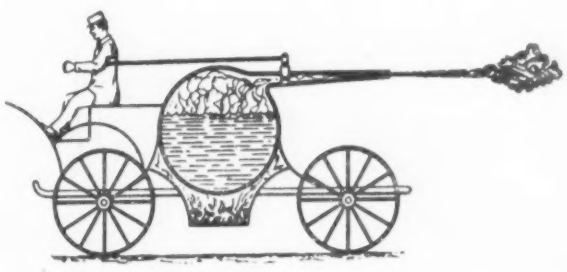
A logical improvement on the Campini system was the gas turbine type of thermal-jet unit devised by Air Commodore Frank Whittle, of Great Britain. Campini used the energy of the expanding gases for propulsion only, but Whittle also employed this energy to drive the compressor, eliminating the need for a reciprocating engine, which was very inefficient for this application. In



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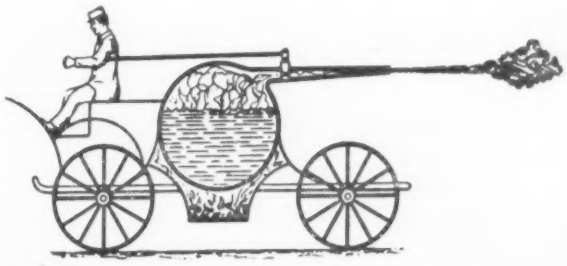


FIG. 2. Jet-propelled vehicle designed by Sir Isaac Newton.

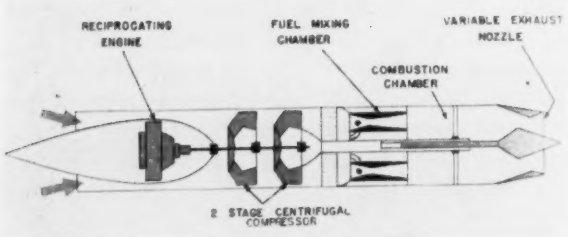


FIG. 3. The Campini system was the first thermal-jet unit of the modern era.

the Whittle design, air is taken in as shown by the arrows in Figure 6. The air is compressed by the centrifugal compressor into the combustion chambers, where the fuel is injected and the gas-air mixture is ignited. The expanding gases that result from the combustion process then pass through the turbine wheel and drive it and the compressor, which is mounted on the same shaft, thus providing more air to maintain the continuous combustion process. Only a part of the energy of the exhaust gases is utilized to drive the turbine and the compressor; the rest of the energy is utilized for the propulsive thrust obtained as a result of the expanding exhaust gases being ejected through the discharge nozzle.

In January 1930, Whittle obtained his first patents on a jet-propulsion engine, but it was not until six years later that the construction of the first engine of this type was started at the Rugby Works of the British Thomas-Houston Company. After two years of development work, the Air Ministry offered the Gloster Company a contract for the first jet-propelled airplane using Whittle's engine. During taxiing tests, the airplane became air-borne, reaching an altitude of 6 feet for 100–200 yards' range. The first official take-off of the Gloster Pioneer E-27, forerunner of the Gloster Meteor, occurred at Cranwell on May 15, 1941, almost two years after the flight was made by the German HE 178. The flight lasted seventeen minutes and was successfully completed.

The U. S. Air Force inaugurated its jet-propulsion program soon after the successful flights in England. In July 1941, a special American technical mission viewed the British-developed jet engine at Rugby. As a result of this investigation, arrangements were made to conduct the development of turbo-jet engines, based on the Whittle design, in the United States. At the time this decision was made, only fifteen flights and ten hours of jet engine operation had been accumulated in Great Britain.

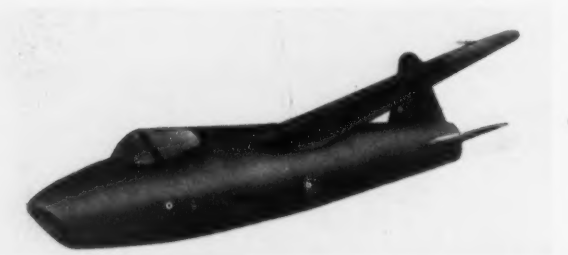
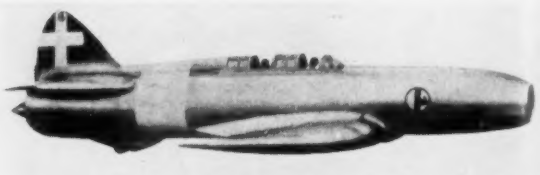


FIG. 4. The Heinkel 178, first jet-propelled propellerless plane incorporating a thermal-jet engine.



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The development of the turbo jet in the United States was entrusted to the General Electric Company because of the experience this company had acquired in the development and production of the turbosupercharger for high-altitude, high-power American reciprocating engines. Essentially, the turbo-jet engine is a large turbosupercharger, incorporating a device for the combustion of the fuel-air mixture. The General Electric Company designed, built, and statically tested its first unit in less than seven months after the first Whittle engine was brought to this country. The General Electric design followed the Whittle lines fairly closely. In October 1942, barely one year after the development of the J-31 (I-16) turbo-jet engine was undertaken, the Bell XP-59A Aircomet incorporating two such engines was flown at a secret test site in the United States. An outgrowth of the J-31 development was the J-33 (I-40) turbo-jet engine. This engine produces 150 percent more thrust than the J-31 and is, at present,

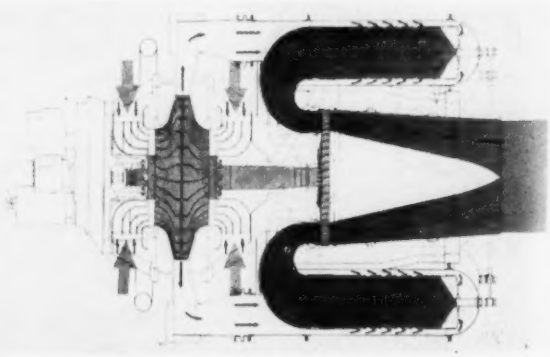

FIG. 6. The Whittle design—schematic.

FIG. 7. The North American B-45, one of the first operational bombers to employ jet propulsion.

in operational use in the F-80 Shooting Star.

Along with the production of turbo-jet engines of the Whittle design, the development of axial flow type turbo-jet engines was conducted in Britain and this country. The principle of operation is exactly the same as that of the Whittle engine. The design of the axial flow compressor, however, consists of a series of rows, or stages, of blades rather than one large centrifugal compressor. This permits the utilization of a compressor of smaller diameter to provide the required amount of air compression and, as a consequence, an engine of smaller diameter which offers the advantage of less drag, in providing greater horsepower per unit of projected frontal area. Most of the operational and experimental jet aircraft of today utilize the turbo-jet engine of either the centrifugal compressor or the axial flow compressor type.

Although the details concerning the numerous fighter and bomber jet aircraft under development cannot be divulged in full, some information has been released on several types of jet aircraft. The first among these is the Republic F-84 Thunderjet which has a speed of more than 590 mph, an operational range of 1,000 miles, and a service ceiling of more than 40,000 feet. This aircraft is powered by the J-35 axial flow turbo-jet engine.

One of the outstanding jet fighter planes of today is North American's F-86 Sabre. This aircraft is a low wing fighter with a sweepback of 35 degrees for both the wing and tail assembly. Its service ceiling is over 40,000 feet, and its combat radius is more than 500 miles. The Sabre has established the world's speed record of 670.981 mph, carrying its normal operational load of ammunition and armament. It is powered by the J-47 turbo-jet engine.

Among the newest jet fighters of the Air Force is the Northrop XF-89 Scorpion. This aircraft is especially designed for tactical operations under unfavorable weather conditions. It has a crew of two, a pilot and a radar observer, both of whom can be "exploded" to clear the plane by pilot-ejection seats if the plane must be abandoned at high speeds. The Scorpion is in the 600-mph speed class and has a service ceiling of over 40,000 feet. Its propulsive system consists of two Allison J-35 jet engines. Another new experimental jet aircraft is the Lockheed XF-90, a penetration fighter which made its first flight test at Muroc Air Force Base, California, on June 3, 1949, staying aloft 37 minutes. It employs 35 degrees of wing sweepback and has a span of approximately 40 feet, a length of 56 feet, and a height of approximately 14 feet. It is powered by two Westinghouse J-34 axial flow turbo-jet engines.

The Republic XF-91 is designed as an interceptor fighter to be used as a local defense weapon capable of combating enemy bombers. Its wings

are swept back and are wider at the wing tips than at the wing and fuselage junction. The inverse taper of the wings will theoretically allow better control of the aircraft at low speeds. Powered by a turbo-jet engine, this interceptor also incorporates rocket motors for accelerated take-off and climb and for operations at high altitudes.

The Consolidated-Vultee XF-92A is the first American aircraft to feature the Delta wing, on which the sweepback is 60 degrees. The wing is triangular in shape and incorporates elevons in the trailing edge for aileron and elevator action. The vertical stabilizer and rudder are provided to give additional directional control and stability. The plane is powered by an Allison J-33 turbo-jet engine.

One of the first operational bombers to employ jet propulsion is the North American B-45 (Fig. 7). Its design is patterned along conventional lines, although they are highly streamlined. Its four J-47 turbo jet engines are arranged in pairs in nacelles on each wing. The airplane was designed to carry a bomb load of over 10 tons, and it has a tactical radius of over 800 miles. It is in the 550-mph speed class. The Boeing XB-47 stratojet is a six-engine bomber with wings swept back to a 35-degree angle (Fig. 8). Four of the engines are mounted in pairs beneath the inboard section of each wing. A single jet unit is positioned at each wing tip. The plane is designed for speeds exceeding 500 mph and has a tactical radius of approximately 1,000 miles. The Martin XB-48 is a light bomber powered by six J-35 jet engines. It is in the 500-mph speed class and has a combat radius of over 800 miles. It is designed to carry more than 10 tons of bombs. An unusual feature of the XB-48 is that its main landing gear is of the tandem type, with an outrigger gear under each wing. The Northrop B-49 is the jet-propelled version of the B-35 flying wing. Powered with eight J-35 engines, this aircraft, the largest USAF jet plane so far built, is in the 500-mph speed class (Fig. 9).

Although the turbo-jet engine is the major source of propulsion for the jet aircraft of today, the rocket and the ram jet will find their application on the supersonic aircraft and guided missiles of tomorrow. A detailed discussion of these two

FIG. 8. The Boeing XB-47 stratojet is a six-engine bomber with wings swept back to a 35-degree angle.

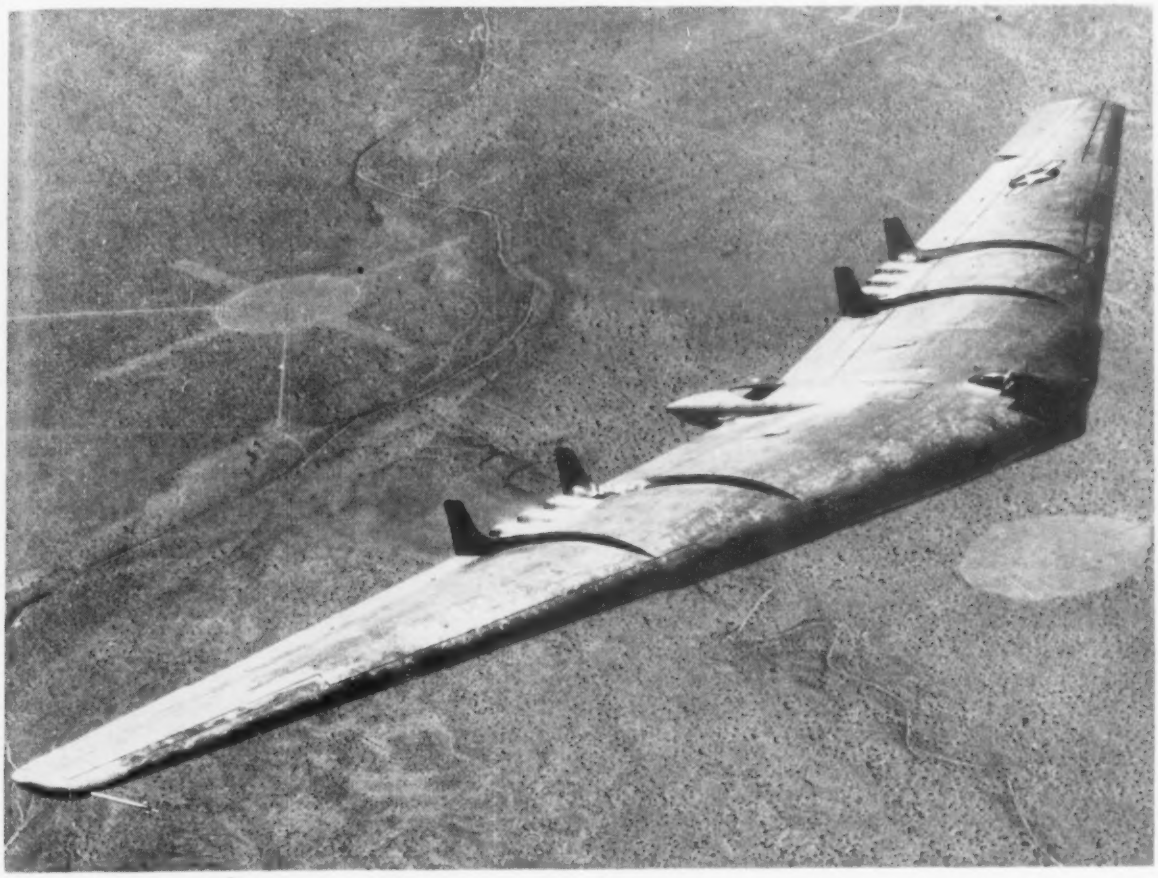

FIG. 9. The Northrop B-49, the jet-propelled version of the B-35 flying wing.

types of jet power plants is not possible within the space limitations of this article. It suffices to point out that the performance being obtained with the rocket-propelled X-1 research vehicle is indicative of the strides being made in conquering the problems of supersonic flight. The phenomenal developments of the past several years have established jet propulsion as a primary type of propulsion for the operational Air Force fighters and bombers of the future.

Jet propulsion is a reality today, but we should not expect an overnight replacement of propeller-type aircraft by propellerless, or jet, aircraft. Many problems remain to be solved. For one, the problem of excessive fuel consumption severely limits the range and payload obtainable with present-day aircraft as compared with the range and payload of a propeller aircraft such as the B-50. Furthermore, the take-off characteristics of jet aircraft are unfavorable as compared to those of propeller-type craft, since the thrust horsepower of a jet is a function of its speed. Thus, extremely long runways will be required for the acceleration of heavily loaded jet aircraft to produce the thrust required for take-off. Obviously, propeller-type engines, whether the conventional reciprocating engine or the turbo-prop engine, lend themselves to application on heavy payload aircraft such as cargo aircraft and transports, which require high power outputs for take-off on comparatively short runways.

None of the problems which face us is insurmountable. The problem of high fuel consumption may be solved by the development of more effective fuels and combustion methods. The problem of take-off is being solved with the development of efficient and dependable rocket jet-assist-take-off units. There is no doubt that the new age of flight heralded by the advent and continuous improvement of jet propulsion offers glowing promise to both military and civilian aviation.

NEW PLANTS FOR OLD

P. S. HUDSON

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EFFORTS to introduce plants from one environment to another have been made ever since man started to cultivate plants at all. Some of the plant introductions made in the past have been astonishingly successful; for example, the Brazilian rubber tree introduced into Ceylon, Malaya, and the East Indies has formed the basis of the rubber industry of the world, and anyone who likes oranges will testify to the success of the introduction of the navel orange from Brazil to California. Potatoes, tomatoes, and tobacco are other examples of plants introduced from South America which have now become almost universal. In many cases, plants introduced from outside have served as a basis for plant-breeding operations; one or more of the valuable characteristics of the introduced form have been transferred to the commonly cultivated forms of the plant by a process of hybridization, followed by patient selection and testing of the resulting hybrids. In this way many of the improved plants we are familiar with in our farms and gardens, in our kitchens and on our dinner tables, have been built up; wheats resistant to rust attack, strawberries with fruits twice the size of those eaten by our grandfathers; beans free from strings; corncobs with beautifully arranged symmetrical grains, ripening at a range of conveniently graded dates, and, incidentally, yielding nearly half as much again as those our fathers grew—the examples could be continued almost indefinitely. From these few instances it may be seen, however, what an important role introduced plants have played and can play in the improvement of our cultivated plants. The possibilities of improvement would seem to be almost unlimited. Most cultivated plants have been improved in yielding capacity by breeding methods; some, such as wheat, cotton, and many horticultural plants, have been improved also in quality. But almost all forms that now exist could be improved still further by breeding; wheat varieties resistant to rust are not always sufficiently free from lodging or shattering of the ear, those free from shattering are not always sufficiently winter-hardy, and so on ad infinitum. The characters it is desired to add can, more often than not, be found in some other variety or form, though often in a form growing in some quite different part of the world. Plant breeders have gradually come to see that one of the first essentials for the success of their task is to have at their disposal the greatest possible choice of types, from as great a range of geographic and climatic areas as possible, and so containing the greatest range of desirable characters that are known to exist in the plant in question. It was this argument that led the Russian botanists in the years between the two world wars to make a survey of the crop plants of the whole world; the results of the survey, carried out by a strong team of competent botanists under the leadership of the late N. I. Vavilov, surpassed all expectations. Rich and quite unexpected sources of economic plants were discovered, and the range of variation within each plant was found to be much greater than had ever been previously suspected. Not only new plant characters or varieties but new species were discovered. Even in wheat, which was one of the most widely investigated of the cultivated plants, several new species, hitherto unknown, were found. In barley, forms were found that were adapted to extreme conditions either of moisture or of drought, others with smooth awns or naked grains, or resistance to the frit fly, and so on. Among fruit trees, apricots that will survive 72 degrees of frost, blackberries with soft spines, edible honeysuckle and mountain ash, frost-resistant vines, and disease-resistant forms of many others are among the interesting types discovered.

An especially interesting example is the potato. We now know that the potato was introduced into Europe as early as the year 1570 or even before, although it was some time before it became generally cultivated. Today it is grown nearly everywhere and is one of man's staple foods. The number of agricultural varieties recorded can be counted in the hundreds. Yet, as far as we are able to judge from the information at hand, all these innumerable varieties have arisen, ultimately, from

the first few tubers that were introduced into Europe three and a half centuries ago; at least there is no evidence to show that any later introductions from South America were made, or, if they were, that they had any material effect on potato breeding. The entire range of types known in our present-day potatoes, then, has arisen by a continuing process of recombination of the characters contained in the original material brought over in Queen Elizabeth's time. What must have been the astonishment of the Russian botanists, therefore, when they sent their expeditions to the South American Andes, to find, growing in the Cordilleras of Bolivia and Peru, hundreds of other potato types, all as different as could be from the potatoes grown in Europe and elsewhere. They found potatoes of all conceivable shapes and sizes, some long and sinuous like a serpent, some small and round, others with curious markings like the head of an animal or a man; tubers of all colors, ranging from inky black through various shades of purple and pink to pale-cream color, were found. There were many differences of flavor and consistency, too. Most of these forms are cultivated by the local Indians and are given distinctive, often highly descriptive names. That these potatoes have been used by the local inhabitants from time immemorial is shown by the discovery among the ancient Indian pottery of quaint vessels in the shape of potato tubers, eyes and all, and of others, more grotesque in shape, where the head of a man or animal is depicted with eyes resembling those of a potato.

From all this the Russians concluded that they had actually found the birthplace of the cultivated potato. Many of the primitive potatoes found by them show surprising resemblances to those depicted in the first published descriptions of the potato by the early herbalists. Their characteristic features have thus been gradually lost in many generations of breeding. Many others, however, have in fact never been known in Europe or the rest of the world, owing to the unrepresentative and random nature of the samples that served for introduction. The practical importance of this discovery lies in the fact that some of these characters that had previously been unknown are of great value to agriculture. One of these is frost resistance; the potato has never been regarded as a hardy plant, but now it is found that frosts occur almost every night in the higher areas of potato cultivation in the Andes (which in places go up to almost 14,000 feet), and that the potatoes come through undamaged. Such hardiness, if it could be transferred to our common potatoes, would enable immense northern areas in countries like Canada to grow potatoes for the first time. We have already seen what terrible consequences the ravages of such diseases as potato blight can have if left unchecked, and so far no satisfactory control for blight disease has been forthcoming. Some of the primitive species of potatoes found in Mexico, however, are immune from blight, and it only remains to transfer this immunity to the domestic races for a complete solution of the problem to be provided. The same is true for Colorado beetle and many other pests.

Enough has been said to show how important the plants collected in these many expeditions can be as a source of raw material for plant breeders to work with in improving our crops. The vast amount of material collected by the Russian investigators built up the most unique store of potential breeding material that had ever been known, and constituted the famous World Collection of Cultivated Plants at the Institute of Plant Industry, Leningrad. Later developments in genetical thought in the Soviet Union have unfortunately somewhat diverted attention from the importance of this world collection, but it served as an example to breeders throughout the world of what can and should be done to supply the plant breeder with the necessary provisions to enable him to perform his task. Unfortunately, no one country has since been in a position to attack the problem on a scale adequate enough to assemble in one spot all the forms existing of all the cultivated plants with which plant breeders may be expected to work. Nor has it been possible to find one spot in the world climatically suitable to maintain all cultivated plants. Individual efforts have been made by countries or groups of countries. The U. S. Department of Agriculture has maintained and enlarged its already admirable collections of a large range of crops; the British Commonwealth has established large collections of potatoes, cotton, cacao, and bananas; and almost every plant-breeding station throughout the world maintains a collection of some sort to serve as a starting point for its breeding operations. This system has the great defect, however, that no collection is really complete, yet many of the more popular varieties of plants are represented over and over again in different collections; lack of coordination results in both duplication and incompleteness.

How, then, can this state of affairs be im-

proved? Clearly, by cooperative effort on the part of plant breeders throughout the world. There have been repeated attempts in the past to organize some such cooperative activity, but they have mostly come to nothing, owing largely to the magnitude of the task and the absence of any centralized body that would be responsible for the organization of it. This fact was brought to the notice of the Food and Agriculture Organization of the United Nations at the organizing convention in Quebec in 1945, and the subject has been further discussed at a number of later meetings. Out of these many discussions, and after much trial and error, there has gradually emerged what appears to be a workable scheme, which has come to be known as the FAO World Catalogue of Genetic Stocks. The scheme has been devised in such a way that each country, or state, is asked to take upon itself the responsibility for maintaining the varieties, races, and breeding stocks of its own territory, and furnishing details of them to the central office of the FAO (Agriculture Division) in Washington, D. C. In this way the burden of the work is distributed between the participating countries, and every one of them is free to benefit from it. A brief description of the scheme and how it works may be of interest.

Before initiating the actual cataloguing of stocks, exploratory work was done by FAO on the most convenient method of describing the stocks, transcribing the data to permanent records, keeping the records up to date, issuing summarized information, and supplying detailed information on request with respect to particular groups of stocks. These things are more or less interrelated, and after considerable study it was decided that the method must be based on a punched-card system of recording. Description forms have been devised which enable a plant breeder to record all the main characteristics of a variety on a single form by simply placing a circle round a code number in the appropriate column. Each column corresponds to a particular character, and the characters are arranged in three main sections. The first section covers Descriptive Classes, the second, Disease and Insect Reactions, and the third, Agronomic and Quality Classes. In the second and third groups there is uniformity in the setting up of the classes in that, with the exception of the zero, *low* numbers indicate *high* desirability. This principle of classifying stocks so that desirable classes are indicated in low numbers throughout was adopted after thorough consultation with plant breeders. Another feature of the classification system is that it is based on a series of classes from 1 to 9. For example, in the case of yield, 1 = *Very High,* 3 = *High,* 5 = *Medium,* 7 = *Low,* and 9 = *Very Low.* With this method the medium class falls exactly in the middle of the range, which it would not do if the scale ranged from 1 to 10. In this way some 60 characters can be recorded without any writing at all, except the inscribing of the circles. Certain other features are recorded by the very minimum of writing.

These forms are sent to plant breeders and breeding institutions all over the world, and, when they have been completed and returned to FAO, the data recorded on them are transferred to punched cards, these cards forming the basis of the World Catalogue. They are easily manipulable, and it is possible to extract from them, by a simple mechanical operation, all or any desired portion of the information contained on them, and if necessary reproduce it. Thus, on the basis of the information supplied from the breeders and incorporated on the punched cards, a list of the catalogued stocks, classified according to their characteristics, will be compiled and circulated to all contributing breeders and, upon request, to others. From examination of these lists a plant breeder will be able to see whether any of the stocks in the catalogue possess properties of special interest, and, if so, complete available information regarding such stocks will be supplied to him by FAO on application. If the breeder desires to secure seed, he will write direct to the station holding the stock. Quarantine regulations of the countries involved will often suggest the best procedure in the exchange of seed, but FAO will give all possible assistance in case of difficulty.

Owing to the magnitude of the task, it was considered desirable that FAO should restrict the scope of its work in the beginning to wheat, extending it as soon as possible to rice, and thus embracing the two greatest food crops of the world. Then, as opportunity and facilities permit, the catalogue will be enlarged to include other self-fertilized crops, especially the other cereals and crops of importance to certain areas, such as soybeans.

An essential part of the scheme is that each breeder or institution participating in it undertakes to maintain living material of the stocks of which he furnishes the details, and to supply small quantities of seed of these stocks to other participants in the scheme. The type of material perpetuated includes not only commercial varieties but also other varieties or races that would be of possible

interest to plant breeders for use as parents, and even hybrid material known to possess one or more valuable genes or characters, such as resistance to some disease, strong straw, high baking quality, or freedom from shedding, sprouting in the ear, or other defects. Since each country is generally expected to maintain only the races of its own territory, the amount of material that falls to the lot of any one breeder to grow for the benefit of the scheme is not large. For cereals, for instance, about a pint of seed from each stock would usually be sufficient to provide a small package for each plant breeder who might request it, and the seed, if properly stored, will remain viable for at least five years. Seed supplies could be maintained, therefore, by growing one fifth of the stocks each year, or 200 short rows per year if the total number of stocks were 1,000. This would be a very small undertaking if the task were assigned to the staff of an institution engaged in plant breeding.

It is anticipated, however, that certain areas may not participate in the scheme, at the beginning, owing to insufficiency of staff or for other reasons. It may happen that some of or all the varieties of these areas are present in one of the large collections already in existence and maintained by one of the plant-breeding institutions in some other country. For this and other reasons any breeder or institution possessing a world collection of wheat or some other plant, or a large collection from other than his own area, is encouraged to maintain it. Such collections can be exceedingly valuable as a source of genetic material. By "processing" the entire collection — for example, by growing it under epidemic conditions for a particular disease organism—resistant plants may be discovered which, when crossed with susceptible but highly productive varieties, can give rise to disease-resistant strains of the latter.

Although the scheme as here described is applicable only to self-fertilized plants, it is recognized that similar treatment should be given to the cross-fertilizing species, particularly among the herbage and forage grasses and legumes, and the brassicas. These types present a number of difficult problems as far as the securing of uncontaminated seed stocks from living collections is concerned, but it is felt that these difficulties are not by any means insurmountable, and that it is desirable that the question of the cataloguing and maintenance of genetic stocks of these crops should also receive consideration by FAO in due course. Special importance is being attached at the present time to forage plants capable of growing in tropical and subtropical areas. The number of head of livestock that can be carried in these areas is more often than not governed by the availability of fodder during certain critical periods of the year. The introduction of certain exotic species such as the kudzu vine and the lespedezas has gone far toward solving this problem in some parts of the United States and elsewhere, but even a casual study of the question shows that the possibilities of development in this direction are by no means exhausted. In fact, some investigators think we are only at the very beginning. At all events, a systematic survey of the existing resources throughout the world, on the lines indicated above, followed by free and extensive interchange of material and results between the research workers and countries involved, is the next logical step and should undoubtedly lead to a more thorough utilization of the plants already available. Promoting the possibilities of interchange of plants between countries with comparable climatic conditions will probably open up new possibilities in introducing entirely new plant species in many of these areas where they are so badly needed.

SCIENCE ON THE MARCH

TREATMENT OF TREES WITH TOXIC CHEMICALS TO FACILITATE REMOVAL OF BARK AND TO REDUCE WEIGHT*

INEVITABLY, mills that make paper pulp from wood have considerable investment in mechanical apparatus for bark removal and in power required for its operation. Anything that facilitates the removal of bark has, therefore, potential interest to manufacturers of pulp and paper.

Treatment of trees with chemicals to facilitate removal of bark has recently engaged the attention of the pulpwood industry, and various tests of the use of chemicals for this purpose have been undertaken by certain companies since early in 1942, the year in which a patent on the use of chemicals for removal of bark from trees was issued. As early experiments showed that the wood of some trees to which chemicals had been applied was lighter in weight than wood of untreated trees, it seemed that chemical treatment might also be capable of effecting economies in transportation by reducing the weight of wood.

This paper presents a brief summary of work by the Forest Products Laboratories of Canada on chemical aids in bark removal and on the effects of such chemical treatment in reducing the weight of wood, together with observations made at the same time on some of the effects on the quality of the wood of treated trees.

Bark may be peeled cleanly from trees during spring or early summer when growth is active, but, when the growing season approaches its end, the bark is no longer easily peeled. In eastern Canada, where the experiments of the Forest Products Laboratory were done, the period during which the bark may be cleanly and easily peeled from freshly felled trees (known commonly as the "sap-peeling" season) ends about the middle of August. Much of the pulpwood felled during spring and early summer is sap-peeled with simple hand tools. The experiments cited show that trees may be killed with chemicals during this season of easy peeling so that the bark retains the easy peeling quality that characterized it at the time it was killed.

The fact that the bark can be easily peeled from trees for about three months between the time when growth begins in spring and ceases in midsummer, has been explained by reference to the soft condition of the cambium during the growing season. In the season when growth is active, the cells of the cambium are actively dividing and may be easily torn, so that this layer presents a region of easy cleavage that permits clean separation of the bark from the wood with a minimum of mechanical effort. Later, as the period of growth ends, the cambium toughens so as to resemble more nearly the adjacent wood and bark. It no longer presents an area of extreme weakness, with the result that it is no longer the region of easy cleavage, and peeling with the usual hand-operated tools is not feasible. Chemicals may be applied to trees during the season of easy peeling so that the cambium is killed while in its active, easily cleaved condition, with the result that the trees so treated may be easily peeled thereafter.

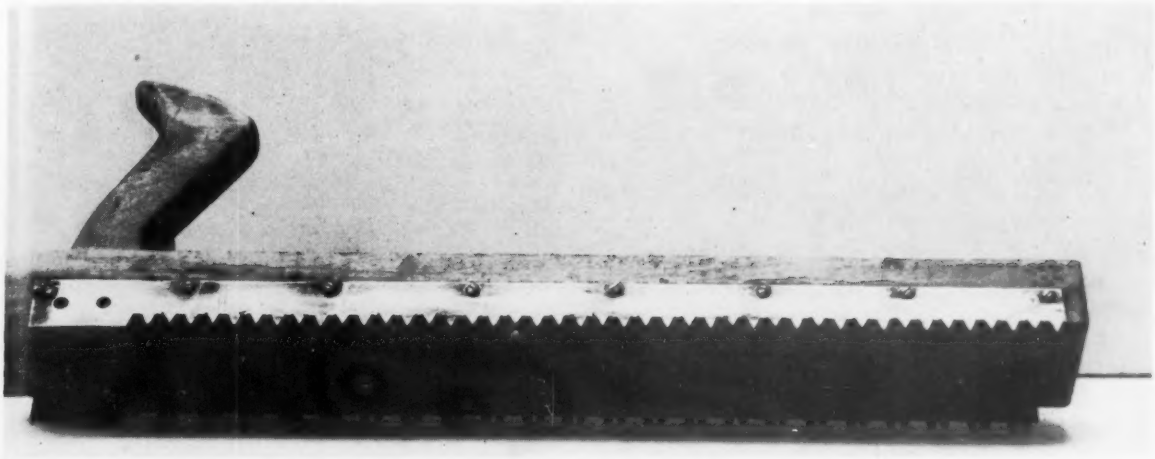
METHODS OF TREATMENT

In order to produce easy peeling by chemical treatment, it was found necessary to apply chemicals to sapwood, exposed all around the circumference of the tree, by removing a strip of bark at a convenient height near the butt. This girdling operation was performed by cutting through the bark with either a special saw or a V-shaped knife. The width of the girdle varied from about 0.25 inch to some 2.5 inches, depending on whether the knife or saw was used.

The chemicals were made into paste with a little water, and sometimes flour, to make the mixtures stick to the wood. In the earlier experiments chemicals were held in close contact with the wood by a band of crinkled kraft paper pulled tight around the tree and fixed in place with a broad-headed upholstery tack, but the most recent tests indicate that a band is not necessary to obtain easy peeling. Such use of chemicals depends on the fact that water-soluble substances can be applied in contact with the wood of living trees so as to be dissolved and absorbed into the ascending sap and taken upward in the sap stream.

Absorption of soluble chemicals so applied to trees takes place fairly quickly when growth is active unless heavy rain immediately after application should wash away materials not protected

* Based on an address presented during the United Nations Scientific Conference on the Conservation and Utilization of Resources, Lake Success, New York, August 17–September 6, 1949.



Double blade (girdling) saw for removing a strip of bark about 2½ inches wide around the tree.

by a bandage. Under favorable conditions, enough material to kill trees and to perpetuate the easy peeling of bark may be absorbed from an application of the most effective chemicals to even the narrowest girdle.

A number of different chemicals were used in experimental treatments, but the best results in effecting easy peeling were obtained with soluble forms of arsenic.† Next best was ammonium sulphamate, widely used in weed-killing compounds. With the most effective chemicals the application of amounts as small as 15 gm (dry weight) was often found to produce effective results on trees of 9-inch diameter at the girdle.

In experimental treatments in which hand methods of girdling and applying chemicals were used, and employing an inexperienced crew, it was estimated that trees comprising 9–12 cords of wood of average pulpwood size were girdled and treated per man-day (eight hours), depending upon the species and general working conditions. Undoubtedly, time studies of large-scale treating operations would indicate that a larger number of trees could be treated per man-day.

Treatments were applied to nine species. In stands where the trees were of pulpwood size, treatments were applied to aspen, *Populus tremuloides* Michx. and *P. grandidentata* Michx.; balsam poplar, *Populus balsamifera* Du Roi; white birch, *Betula papyrifera* Marsh; Balsam fir, *Abies balsamea* (L) Mill.; black spruce, *Picea mariana* (Mill) B.S.P.; white spruce, *Picea glauca* (Moench) Voss; and jack pine, *Pinus banksiana* Lamb. Treatments also were applied to cedar of sizes suitable for posts and poles (*Thuja occidentalis* L.).

† Particularly a mixture of arsenic trioxide with caustic soda. Commercial sodium arsenite also proved effective.

RESULTS

Soluble arsenic applied to trees during June and July rendered the bark easy to peel when the trees were felled after the sap-peeling season was over, but the peeling became easier if trees so treated were allowed to stand until about the middle of October.

In general, trees of the broad-leaved species treated with arsenic in June and July peeled more easily than sap-peeling when felled the following October. Trees of the coniferous species treated with arsenic in June and July, and even as late as the first week of August, generally peeled more easily than sap-peeling when felled in the following October, the bark in some instances coming off in such large pieces as to permit peeling by hands alone without the aid of tools. Chemical treatments that gave easy peeling by October were found to continue their effects the following year.

Trees to which arsenic treatment was applied too late to permit easy peeling during the following autumn improved in ease of peeling if allowed to stand for a year. With the exception of aspen and birch, the bark of trees so treated could be very easily removed in the autumn a year after treatment, and in aspen and birch could be removed about as easily as from untreated trees during the season of easy peeling.

The greatest reduction in average weight‡ of peeled wood was found in chemically treated jack pine and balsam fir; wood of black spruce was not appreciably lighter for its treatment. The small loss of weight of black spruce seems associated with the very narrow sapwood of this species,

‡ Reduction in weight of wood took place above the level where chemicals were applied. Wood below the girdle did not lose weight and was typically heavier than in untreated trees.

since white spruce, which has wider sapwood, showed satisfactory reduction of weight comparable to that observed in jack pine. The weight of small cedars was reduced in one summer to an amount about 15 percent less than untreated cedar. Trees of the broad-leaved species showed no reduction in weight during the summer and autumn after treatment.

June and July were found to be the best months for applying chemicals to jack pine and balsam fir in order to effect appreciable weight reduction by October of the same year. For example, peeled wood of jack pine treated in June and felled in October of the same year averaged over 10 pounds per cubic foot lighter than normal untreated trees felled during the same period. Based on an average of 88 cubic feet of solid wood per cord of jack pine, this would mean a reduction of about 900 pounds per cord effected four months after treatment. Late treatments (made during early August) were not as effective in reducing the weight of wood and trees treated in September and, sampled one month later, showed no reduction in weight. Allowed to stand for a year after treatment, however, such trees showed considerable loss of weight.

Examination of preliminary results of experiments carried out during 1947 and 1948 has shown that trees of jack pine and balsam fir treated with chemicals at any time from June to September continue to lose weight throughout the year following treatment. Trees of jack pine treated in June and July showed a loss in average weight of wood of about 17 pounds per cubic foot when felled in September of the year following treatment, and those treated in August and felled during the same period showed a reduction of about 12 pounds per cubic foot. .

Trees of black spruce and broad-leaved species treated from June to September and felled during the early summer of the following year showed no appreciable reduction in weight.

Traces of bark insects were sometimes observed, particularly in the conifers (with the exception of cedar), in trees treated during June or July and felled during the first summer. Trees in which chemical treatments were most effective in reducing weight generally had the most bark insects,

Left: The strip of bark is removed. *Right*: Treatment completed, bandage is secured with white upholstery tack.

A gasoline-powered girdling tool in operation.

especially in top logs where the greatest reduction in weight typically occurred. Trees treated with ammonium sulphamate were much more severely attacked than those treated with arsenic, which evidently had some toxic effect on insects. The attack by bark insects in such trees treated with sulphamate was sufficient to cause the bark to break along the insect tunnels and peel in small pieces so that removal of the bark with the usual peeling tools was more difficult than in trees treated with arsenic.

Some trees of the coniferous species, especially jack pine, treated in June or July, showed considerable attack by wood borers in top logs when felled in October of the same year. Trees treated late in the year (in September), although showing no attack by wood borers when tested a month following treatment, showed traces of attack when felled the following June, the attack becoming more severe during the warm summer, as shown by observations made when such trees were felled in September (a year after treatment). Trees of the broad-leaved species felled a year following treatment also showed some attack by wood borers.

Traces of blue stain were found in sapwood of coniferous species, treated in June or July and felled in October of the same year, the attack being more severe in the top logs of trees of jack pine where considerable drying had taken place. Sapwood of some trees permitted to stand through two summers after treatment showed signs of decay.

Trees treated with chemicals late in the sap-peeling season tended to show less attack by insects and stain when felled in the late autumn than those treated early, the amount of such attack depending upon the length of time the trees were left standing during the warm summer months. In no case was the presence of wood borers and blue stain considered so severe as to degrade the wood significantly for pulp.

The small amount of the chemicals that enter the sap stream of treated trees would seem insufficient to prevent stain or attack of insects on the sapwood. The fact that treatment with arsenic keeps trees so treated comparatively free from bark insects during the first summer after treatment is of interest since such insects were found in considerable number in trees treated with chemicals lacking the toxicity of arsenic. The effectiveness of soluble arsenic in the tests reported makes it the logical standard of comparison for other chemicals that may be tried in future for similar purposes. Arsenic has, however, the disadvantage of causing its handlers to develop painful rashes unless the most extreme care is taken to avoid its contact with the skin. Moreover, its extreme toxicity makes it a possible source of danger to animal life unless substances repellent to animals are mixed with it.

It does not seem too much to expect that other suitable substances may be found that are capable of producing as easy peeling as arsenic, that will be more effective as inhibitors of insects and staining fungi, and that can be more easily and safely applied.

Recently a gasoline-powered portable tool for girdling trees has been developed that is reported to be satisfactory. The fact that such a tool is capable of making a deep cut in girdling trees may increase the drying of wood of species that so far have not been readily susceptible to reduction in weight by application of chemicals to superficially girdled trees. This, coupled with the fact that the most recent tests show that easy peeling can be produced by applying chemicals without a covering band of paper, should accelerate treating operations. If chemical treatment is to become widely established in industry, possibilities of increased efficiency will of course be sought.

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GAS TURBINES FOR VEHICLES

IF ONLY a small part of the time and money expended by the automobile industry on the development of the reciprocating engine were to be applied to gas turbine development, a highly efficient, reliable engine, with improved performance at reduced cost, would soon be available to the American public. Development of high-temperature alloys and high-efficiency air compressors places the gas turbine on a competitive basis with the reciprocating engine for such vehicle applications.

Steady progress has been made in the development of gas turbines, and the question arises whether such turbines can be successfully applied to vehicle propulsion on a competitive basis with present reciprocating engines. The gas turbine offers several distinct advantages. Comparisons of present and future performance are illustrated in Table 1.

Although most gas turbine research and construction have been on units of 1,000 HP and larger, there is some interest in smaller units, especially in Czechoslovakia and England, where automotive gas turbines have been built. In the United States a 200-HP unit weighing 150 pounds has been developed. It has a diameter of 10 inches and a maximum combustion temperature of 1,500° F.

Application of the gas turbine to automobiles can effect a saving in weight of the engine of 50 percent. Since a reduction of one pound in engine weight will enable designers to reduce the weight of the chassis by another pound, a material saving in weight and cost of motor vehicles can thus be realized.

It is difficult to visualize a more complicated propulsion device than a reciprocating engine, in which energy from fuel is converted into mechanical work through the effort of pistons, valves, crankshaft, and flywheel, then used to drive either a complicated automatic mechanical transmission or a fluid generator which in turn drives a fluid pump and finally a speed reducer at the rear wheels. The only excuse for such a complicated mechanism is that it works with acceptable performance.

In comparison, the gas turbine for automobiles offers a simple device consisting of a prime mover and torque converter in a single unit, requiring only two rotating elements and a single speed-reducer. It is one of the few prime movers that are capable of producing high starting torque at low speed.

Figure 1 shows the performance of a nonregenerative gas turbine designed for the following conditions:

95 HP at 83 mph (same as reciprocating engine)
Temperature at design point—1,500° F.
Compressor efficiency—80 percent
Compressor-turbine efficiency—85 percent
Power-turbine efficiency—85 percent
Combustion efficiency—95 percent
Pressure losses—2.5 percent
Pressure ratio of compressor—3.4 : 1
Inlet air temperature—60° F.

On a level road this turbine would propel the vehicle at 83 mph with a gas temperature of 1,500° F. At 68 mph the gas temperature would be 1,200° F. and at 58 mph, 1,000° F. The torque multiplication—that is, the torque at zero speed divided by the torque at maximum speed—is 2.75. Although

TABLE 1

	Present Reciprocating Engines		Present Gas Turbines	Future Gas Turbines
	Manual Gear Shift	Automatic Transmissions	Without Regenerator	With Regenerator
Mi. per gal.	15–18	8–14	9–11	16–18
Wt. per 100 HP	500	600	150	200
Cost per 100 HP, $ (high prod.)	250	350	150	200
Advantages	Economical, quiet, simple control	Smooth operation, quiet, low driving fatigue	Small size, light weight, low cost, smooth operation, few parts, low-grade fuel, low oil consumption, excellent torque characteristics	Economical, moderate cost, smooth operation, few parts, low-grade fuel, low oil consumption, excellent torque characteristics
Disadvantages	Gear shifting, plumbing difficulties, highly refined fuel, oil contamination	Poor fuel consumption, expensive, plumbing difficulties, complicated mechanism, highly refined fuel, oil contamination	High-speed reducer, noise, poor fuel consumption	High-speed reducer, noise

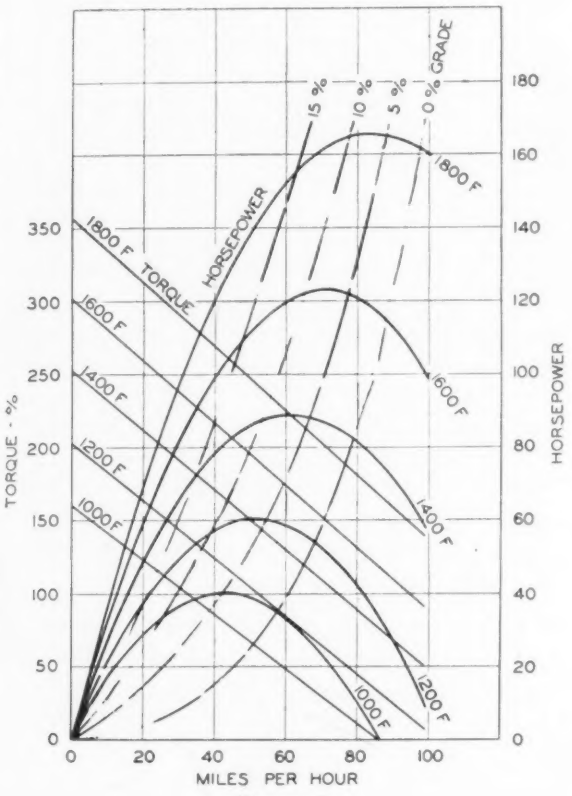

FIGURE 1

this is less than the over-all torque multiplication of the gear transmission of an automoble in low gear, it is more than adequate to negotiate a 15 percent grade.

The power turbine, which is connected directly to the axle through a gear reduction, will operate at speeds from zero to maximum. The compressor-turbine wheel, however, operates at nearly constant speed. Thus the compressor and its turbine wheel act as a producer of high-pressure, high-temperature gas. Control is effected by reducing the speed of the compressor turbine, thereby reducing the pressure ratio, temperature, and air flow through the unit. The speed reduction of the gas producer need not be large to accomplish adequate control. A change in speed of the compressor of less than 20 percent will permit operation of the power turbine over its full range of speed.

A study of Figure 1 will indicate the suitability of the gas turbine to vehicle propulsion. Turbines have characteristically parabolic horsepower curves; efficiency curves are approximately the same shape. With control by gas-produced speed variation, the grade curves fall near the loci of maximum efficiency and horsepower. If the design point is selected at the peak of a given horsepower curve, say, one corresponding to 1,500° F., the torque multiplication is 2:1. By designing the turbine for a blade-speed/jet-velocity ratio somewhat above the ratio of maximum efficiency, the grade curves will fall reasonably close to the peaks of the horsepower curves over a range of grade curves, and the torque multiplication becomes greater than 2:1. Shifting the design point beyond the peak of the horsepower curve causes a small increase in fuel consumption on a level grade, but improves fuel consumption considerably on steep grades. Also, a slightly larger turbine is required.

A vehicle requires maximum power and maximum torque for less than 1 percent of its operating life. To obtain high torque output for short intervals, the gas temperature may be raised above the design temperature. If the gas temperature is raised to 1,800° F., the torque multiplication becomes 3.55:1. This procedure is analogous to supercharging aircraft reciprocating engines during take-off wherein a time limit is set during which the intake manifold pressure may be raised above normal.

With regeneration, the fuel consumption is materially improved. The mpg reach values comparable with many automobiles and light trucks now in operation. The principal advantages of the gas turbine drive are its excellent torque characteristics, eliminating automatic transmissions, freedom from plumbing difficulties, no need for antifreeze, low consumption of lubricating oil, light weight, small number of moving parts, and ability to use fuels that do not require a high degree of refining—for example, low octane number, etc.

There are many problems to be solved before the gas turbine becomes a practical machine that is competitive with the reciprocating engine for vehicle propulsion. Among these are component efficiencies when parts are made small, high-speed gearing, noise, effect of dirt deposits, and low-cost production techniques. However, progress to date on gas turbines indicates that these problems can receive adequate solutions.

Other problems involved in the successful application of gas turbines to vehicle propulsion are noise and vibration, cost, control, starting exhaust-gas dissipation, air consumption, stresses, fuel system, and weight. The noise problem is particularly troublesome, because much of the noise is air-borne and originates in the compressor, but because it is high in pitch and therefore easy to absorb, sufficient research should find a solution to this problem. Since there are only two high-speed rotating parts in perfect balance, vibration does not become objectionable, nor is it harmful.

Cost of an automotive turbine on a production basis should be low. The high cost of present turbines is due primarily to development expenses.

Since the cost of the engine is a small part of the total, it has only a small effect on the over-all cost of the vehicle.

Control of gas turbines over a range of speed and load is not easy. Adequate controls are becoming more complicated and costly. Fuel nozzle research to date has brought on complications rather than simplification. But a gas turbine for a vehicle needs a single control for the fuel, combined with a temperature limiter and an overspeed control. Small gas turbines already in operation may be brought from a starting state to full load in fifteen seconds, and after starting the compressor turbine the power turbine may be accelerated from stall to full speed in five seconds. An electric starter is required to accelerate the compressor turbine to about 25 percent of rated speed. Ignition is required for only a few seconds at starting. Starting can be made easier by opening a by-pass between the two turbine wheels so the compressor turbine can use the full pressure ratio during starting.

The gas turbine uses about seven times more air through the machine than does an equivalent reciprocating engine; therefore, there is seven times as much exhaust gas. The exhaust gas from the gas turbine is cooler, however, than the exhaust gas from a reciprocating engine, and this is especially true if a regenerator is used. Including the air requirements for engine cooling of reciprocating engines, the air requirements for the two types of engines are about equal. Hot gas flowing from the rear of a gas-turbine-propelled vehicle is no different than that from a conventional automobile.

The turbine blades are subject to high stresses, and a mechanical failure of a blade presents disastrous results. Such troubles can be avoided by adequate design and sufficient preliminary testing, with perhaps new parts installed at predetermined intervals. Alloys having 0.1 percent creep in 3,000 hours under a stress of 30,000 psi at 1,350° F. are available at present. If blade-vibration fatigue is eliminated, these alloys are adequate for the life of a vehicle.

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"ORLON" ACRYLIC FIBER

ACRYLONITRILE polymer was first recorded in the chemical literature many years ago and was described as being intractable, infusible, and insoluble, thus leading to the belief that it was three-dimensional in structure. The origin of the "ORLON"* acrylic fiber prepared from this polymer occurred in the discovery in the laboratories of the Du Pont Company that polyacrylonitrile was soluble in certain organic solvents, producing concentrated solutions amenable to conventional yarn-spinning techniques. The initial work on this new fiber disclosed that is was orientable, leading to strong structures, dimensionally stable, resistant to common solvents, acids, dilute bases, and ultraviolet light, and had commercially valuable aesthetic properties. This singular combination of properties justified an intensive search for a suitable commercial process of manufacture. The first phase of this work included a broad search for a solvent from which the polymer could be spun. This effort culminated in the issuance of several Du Pont patents,[1] disclosing a variety of materials possessing solvent and plasticizer character for polyacrylonitrile and its copolymers containing up to 15 percent modification. Investigators elsewhere were also successful in finding solvents for polyacrylonitrile, as revealed in their issued patents.[2]

The polyacrylonitrile used for spinning into Orlon yarns for industrial outlets can be prepared by polymerizing acrylonitrile with peroxygen-type catalysts. Since the polymerization reaction is sensitive to minor amounts of impurities, it is essential to control the conditions of polymerization rigorously, to produce material of uniform properties suitable for uninterrupted spinning. After polymerization and purification, the polymer is blended to level off the minor variations in properties that may occur.

Early in the Orlon acrylic fiber development, an economic analysis of the conventional methods of yarn spinning, together with consideration of product properties, favored the formation of filaments according to the principles of dry spinning. This consists in the precise metering of the concentrated polymer solution through a spinneret into a hot evaporative medium, to remove the major portion of the solvent, thereby forming the solid yarn.

The residual solvent remaining after the spinning operation is removed by extraction with water. Following extraction, the yarn is drawn several times its original length. This process of attenuation aligns or orients the polymer molecules along the filament axis, thus allowing inter-

*"ORLON" is the trade-mark used by Du Pont to designate its acrylic yarn and staple.

molecular forces to become established, increasing yarn strength. Dimensional stability is imparted to the yarn by allowing it to relax a controlled amount after the drawing operation. The strength, elongation, and other physical properties of the yarn can be altered within wide limits by proper adjustment of the extent of drawing and relaxation. After winding on a suitable package, the yarn is ready for shipment to customers' mills for textile processing.

Physical properties. Orlon acrylic fiber has a warm, dry, luxurious hand, coupled with a subdued luster and good dimensional stability. These attributes give this fiber the feel and appearance of silk. It has a high bulking power, which is partly due to the cross-sectional characteristics of the filament. As shown in Figure 1, these are "dog-bone" or "clover-leaf" in shape.

Typical physical properties for the present commercial fiber are shown in Table 1. These properties may be varied over a wide range by changes in the processing history. Similar data are listed for nylon and cellulose acetate fibers for comparative purposes.

Electrical properties. The electrical properties of this fiber are not particularly notable at less than microwave frequencies. In the frequency range 10^2–10^6 cycles per second, the dielectric constant is 5.0–4.0, and the dissipation factor is 0.09–0.03. In the microwave frequency range, the combination of low loss tangent, a low dielectric constant, and low moisture absorption is notable. The extreme resistance of this fiber to fungi and soil-organism attack is also of interest in considering electrical applications.

TABLE 1

	ORLON	NYLON	ACETATE RAYON
Specific gravity	1.17	1.14	1.33
Tenacity,* gpd (Suter)			
Dry	4.0 – 5.0	4.5 – 7.5	1.1 – 1.5
Wet	3.6 – 4.5	4.0 – 6.5	0.7 – 0.9
Loop	3.3 – 3.7	3.9 – 6.0	0.8 – 1.2
Knot	2.7 – 3.3	3.8 – 6.0	0.8 – 1.2
Elongation, % (Suter)			
Dry	16 – 21	14 – 28	20 – 27
Wet	16 – 22	17 – 30	28 – 35
Loop	11 – 17	10 – 13	13 – 20
Knot	8 – 13	9 – 12	13 – 20
Tensile strength (psi)	59,000 – 74,000	65,000 – 110,000	19,000 – 25,000
Instantaneous elastic recovery,** %:			
From 2% stretch	97	100	87
From 4% stretch	84	100	83
From 8% stretch	75	100	55
Retarded elastic recovery,*** %:			
From 2% stretch	85	100	72
From 4% stretch	66	100	44
From 8% stretch	57	99	23
Stretch resist., gpd (at 1% el.)	0.70	0.31	0.45
Moisture regain, % (at 60% R.H.)	0.9 – 2.0	3.4	5.4
Shrink., % (30 min., boiling water)	2 – 4	8.0	2.0
Flex life, cycles (Masland)	316,000	380,000	200

* The tensile strength at the breaking elongation is expressed in grams per denier where the denier is the weight in grams of a 9,000-meter length of the test sample.

** Sample stretched and then allowed to recover for 60 seconds.

*** Sample stretched, held for 100 seconds, and then allowed to recover for 60 seconds.

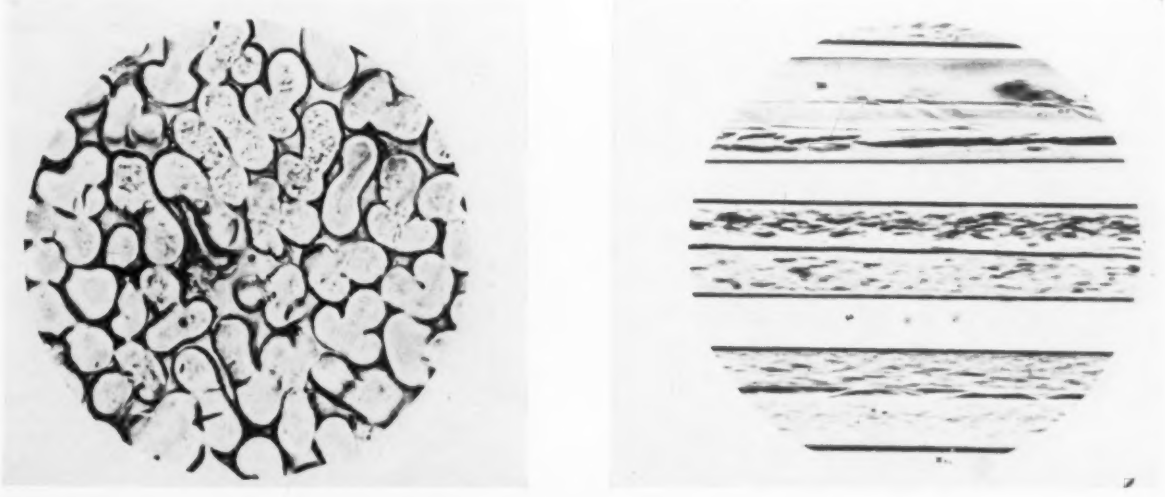

FIG. 1. Photomicrographs (×500) of Orlon acrylic fiber. The cross-sectional view on the left shows "dog-bone" and "clover-leaf" filament shapes. Longitudinal view on the right shows characteristic rough striated surface.

Thermal properties. The resistance of Orlon to burning is between that of cellulose acetate and viscose rayon. It does not flash burn, and the combustion products are no more toxic than those from silk or wool. The softening point† and zero-strength temperature‡ are high, and the high-temperature durability is good. The sticking temperature, as measured on a copper block under 200-gram load and 15-second exposure, is 235° C, as compared with 190° C for cellulose acetate and 220° C for nylon. The temperature at which the fiber bursts into flame was determined to be less than 500° C for cellulose nitrate, 750°–800° C for viscose rayon, 800°–850° C for cellulose acetate, and 950°–1,000° C for Orlon. These may not be taken as true ignition temperatures because of the possibility of an absolute error due to the rapid heating rate employed, but their relative order is correct.

The fraction of room temperature tenacity retained at elevated temperatures is given in Table 2. These data were obtained by immersing the sample in silicone oil at the indicated temperatures and measuring the tenacity in the usual manner. They do not represent thermal degradation, but rather the reversible thermal weakening of the interchain forces which are responsible for fiber tenacity.

TABLE 2

PERCENT OF 25° C TENACITY RETAINED AT ELEVATED TEMPERATURE

Temperature (°C)	Tenacity Retained (%)
− 40	135
+ 25	100
+ 75	85
+100	70
+125	60
+150	40
+175	15
+200	10

Prolonged exposure to elevated temperatures darkens the fiber, but causes little loss in tenacity until a temperature of 150° C is exceeded, as seen in Table 3.

Durability properties. In addition to good high-temperature durability, Orlon acrylic fiber has excellent resistance to outdoor exposure, to acidic and neutral chemicals, and to insect and microorganism attack. It is not particularly resistant to alkaline chemicals.

Representative chemical durability data are given in Table 4.

† The temperature at which viscous flow changes to plastic flow.

‡ The temperature at which the tenacity falls to some prescribed level, generally 0.1 gram per denier.

TABLE 3

HIGH TEMPERATURE DURABILITY—HOT AIR EXPOSURE*

Temp. (°C)	Exposure Time (Days)	Straight Tenacity/Elong. (gpd/%)	Loop Tenacity/Elong. (gpd/%)
Unexposed	—	4.7/15	2.95/10
100	1	5.1/17	3.15/11
	4	5.1/17	3.45/11
	11	4.8/16	3.25/11
	32	5.2/17	3.00/10
125	1	5.0/16	3.10/10
	4	5.1/17	3.20/11
	16	5.0/17	3.05/10
	32	5.1/17	2.75/10
150	1	5.0/17	3.15/11
	4	3.9/15	2.75/10
	8	2.8/11	2.40/ 9
	16	1.3/ 3	2.40/ 9
175	1	2.3/ 9	2.00/ 7

* Exposure in oxygen-free atmosphere will show even less degradation than shown in above table.

Common commercial fibers would not withstand the action of these chemicals at the concentrations employed for more than a few days. Exposure for two months at room temperature to toluene, naphtha, gasoline, ethyl acetate, ether, "Triclene," acetone, and ethanol had no effect on Orlon.

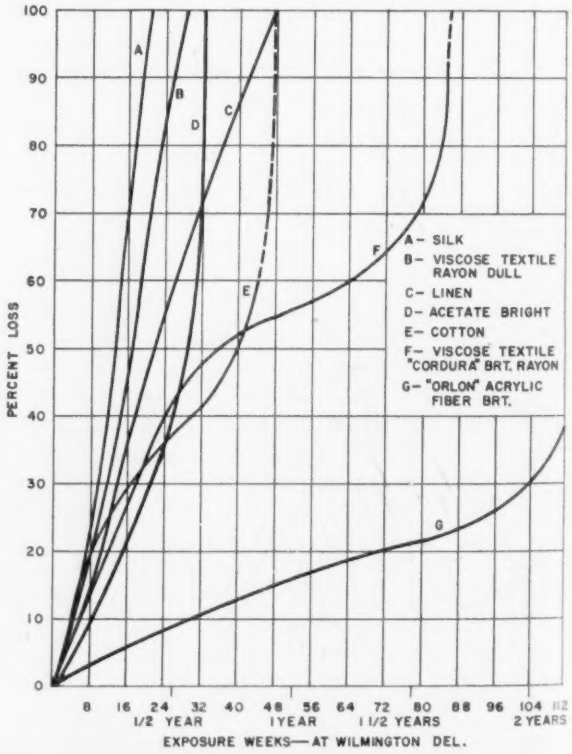

FIG. 2. Effect of outdoor exposure on the tenacity of various natural and synthetic fibers.

TABLE 4

CHEMICAL DURABILITY

Reagents	Conc. (%)	Temp. (°C)	Period of Stability* ORLON
Aqua regia	100	25	No change after 105 days
	50	75	" " " 16 "
Hydrochloric acid	37	25	" " " 20 "
	18	75	" " " 16 "
Hydrofluoric acid	48	25	" " " 56 "
Nitric acid	40	25	" " " 105 "
Sulfuric acid	50	25	" " " 30 "
	37	25	" " " 80 "
Sodium hydroxide	10	25	" " " 10 "
	5	25	" " " 30 "
Zinc chloride	50	25	" " " 105 "
	30	80	" " " 35 "

* Stability defined as less than 15 percent tenacity loss.

Good resistance of Orlon acrylic fiber to commercial bleaching treatments is shown by the data presented in Table 5. Each treatment was several times more severe than normally applied during commercial laundering.

TABLE 5

EFFECT ON TENACITY OF REPEATED BLEACHING

No. of Bleaches	% Loss in Dry Strength	% Loss in Wet Strength
30	2 – 5	6 – 22
60	4 – 6	9 – 26
100	7 – 14	11 – 22

This fiber has outstanding resistance to the degradative effects of ultraviolet and sunlight exposures. Fade-Ometer (ultraviolet light) exposures of 1,000–1,500 hours are required to produce a 10 percent tenacity loss in Orlon, whereas cellulose acetate (bright) shows a similar loss in 300–500 hours, and viscose (bright) in 100–300 hours. Outdoor exposure data secured at Wilmington, Delaware, are shown in Figure 2. The resistance of Orlon is unique.

Data on the resistance of Orlon to microflora, teredos, and fabric insect pests are shown in Table 6. The resistance of Orlon to these agents is seen to be outstanding.

Dyeability. Orlon acrylic fiber is hydrophobic, and consequently its response to conventional dyeing procedures is generally different from the rayons and natural fibers. Pastel shades of good washfastness can be secured with certain acetate and basic colors using orthodox dyeing procedures at the boil. Medium shades can be obtained with these same dyestuffs by using an assistant such as meta cresol in the dye bath. Heavier shades can be secured by dyeing under 15–20 pounds pressure (gauge). Acetate, basic, and certain vat colors may be printed using the usual methods followed by steam aging under 15–20 pounds pressure (gauge). Modified fibers dyeable to deep shades with a wide range of colors by orthodox techniques have been produced in experimental quantities.

Manipulation of properties. As mentioned earlier, Orlon is a completely synthetic fiber. Modification of the several processing steps between the initial volatile monomer and the final yarn provides a wide spectrum of yarns of differing physical properties. A few of the process changes which can be made to give modified yarns may be only briefly discussed here.

The polymerization may be controlled to give a polymer of almost any desired molecular weight. The molecular weight at present used has been selected to yield a desirable combination of final yarn properties and process operability.

Valuable tensile and aesthetic properties are imparted to Orlon by the drawing operation which orients the polymer chains. Unlike nylon and certain other synthetics, Orlon does not have a definite draw ratio§ beyond which breakage of the fiber always occurs. With Orlon high draw ratios are possible because of the large amount of plastic flow which occurs during drawing, in addition to the orientation process. The ten-

TABLE 6

MICROFLORA, TEREDO, AND FABRIC-INSECT-PEST RESISTANCE

Test Condition	Observations
Soil burial (tropical microflora, 21 days)	No tenacity loss
Soil burial (ropes for 18 weeks)	8% tenacity loss
Sea water immersion (ropes for 6 months, heavy teredo infestation)	11% tenacity loss, no teredo damage
Pest defilement:	
American cockroach (7 days)	No tenacity loss
German cockroach (69 days)	No tenacity loss
Pest subsistence:	
Firebrat (20 days)	No damage
Carpet beetle (20 days)	No damage
Clothes moth (20 days)	No damage
German roach (30 days)	No damage
Pest starvation:	
Firebrat (40 days)	No damage
Carpet beetle (50 days)	Slight damage
Clothes moth (33 days)	No damage
German roach (32 days)	No damage

§ A draw ratio of 5 produces an extension during drawing of 500 percent.

sion conditions within the fiber structure during the drawing operation are also important in determining the final yarn properties. X-ray studies indicate that the drawing tension affects the extent or degree of order within the structure, but not the amount.

After drawing, the fiber may be relaxed in order to gain additional toughness and thermal stability. Relaxation causes an increase in orientation as well as in the amount of ordered material. In addition, order is extended to other planes within the fiber. It is not surprising, therefore, that many fiber properties are affected by the extent of relaxation, the relaxing tension, the medium employed, and the temperature at which it is carried out.

Suggested markets and future development. An examination of the above properties of Orlon acrylic fiber immediately suggests certain applications. Its strength and great resistance to heat, acids, microorganisms, and outdoor exposure suggest uses in acid-resistant clothing, hydraulic and pneumatic filtration of acidic materials, automobile tops, awnings, curtains, yacht sails, and sewing thread for fertilizer bags, awnings, tents, tarpaulins, and other similar items.

The fiber's high covering power, good dimensional stability, pleasing hand, drape, and rapid drying suggest uses in suitings, rainwear, lingerie, shirtings, uniforms, and beach wear.

At the present time, continuous-filament yarn is produced on a pilot-plant scale for market development. The evaluation of experimental quantities of staple fiber has shown that such a material will also find a field of usefulness. The process for producing staple fibers differs from that of the continuous-filament yarn not only in the fact that the material is cut into short fibers of the required length, but also in the subsequent processing operations. The object in making a staple fiber is to achieve good processability from fiber to yarn by the conventional systems, and at the same time impart to the end product, be it woven cloth or a knitted structure, warmth, loftiness, pleasing hand and drape, good resilience, and other desirable properties. To accomplish this, it is necessary to impart a crimp to the fiber, either by a chemical or mechanical means.

By appropriate changes of the spinning and other processing conditions, staple fibers possessing properties ranging from silklike to wool-like can be produced. Undoubtedly, this development will assume a greater importance as the work progresses.

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BOOK REVIEWS

OF HUMAN BONDAGE

The Situation in Biological Science. Anonymous. 636 pp. $5.00. International Publishers. New York.

THIS book, said to be the complete stenographic report of "The Proceedings of the Lenin Academy of Agricultural Sciences of the U.S.S.R., July 31–August 7, 1948," was printed and copyrighted in the United States in 1949. Although nowhere so stated in the volume, it is a photolith duplicate of an edition that appeared earlier in Moscow. The text constitutes the documentation for the article by Robert C. Cook entitled "Walpurgis Week in the Soviet Union" that appeared in THE SCIENTIFIC MONTHLY for June 1949. Other reports on the purge of "anti-Michurinists" appearing in the press and in the *Bulletin of the Atomic Scientists* for May 1949 were based on the less complete accounts printed in *Pravda*. This purported *procès-verbal* amplifies the Russian newspaper articles.

The translation is in good English. Faults in use of technical terms or in the rendition of scientific concepts are few, and we may judge that the statements of the speakers are faithfully presented. This book will give anyone who may have thought American reviews and comments on these proceedings to be biased, overdrawn, or nonfactual full opportunity to verify from an authorized USSR publication that the situation is, indeed, as depicted.

The general meeting of the Lenin Academy of Agricultural Sciences was dominated by its president, T. D. Lysenko. He welcomed newly created members of the Academy, named the chairman of the sessions, and then gave the keynote address from which this volume takes its title. The speech was a typical Lysenko harangue, repeating views not essentially different from those of his latest pamphlet, *The Science of Biology Today*, which was reviewed in *Science*, April 22, 1949. Evidence of increased confidence in his power is shown in this speech. First, he boldly criticizes Darwinism as accepted and taught in the USSR, apparently feeling amply protected by Frederick Engels' dialectic arguments of the same tenor. Thus, "Malthusian" errors of Darwin are attacked and the teaching of natural selection belittled as "a summation of age-old practical experience of plant and animal breeders who, long before Darwin, produced varieties of plants and breeds of animals by the empirical method" (p. 12). Some future contender for his place in the sun may seize upon this outright anti-Darwinism of Lysenko to unhorse him. In the second place, Lysenko now feels secure enough to announce without equivocation his adherence to Lamarckism and his belief in the inheritance of acquired characters, matters previously not mentioned in his addresses and not admitted when challenged. These are advocated and put forward as sanctioned by Darwin and Michurin. Belief in the inheritance of acquired characters now becomes the shibboleth to identify Lysenko adherents.

The real purpose of the conference was revealed by the denunciations by Lysenko of fellow-members of the Lenin Academy—I. I. Schmalhausen, B. M. Zavadovsky, and P. M. Zhukovsky—for teaching false Darwinian doctrine (*sensu* Lysenko) and as "Mendelist-Morganists." Other prominent Russian biologists were similarly denounced, among them N. P. Dubinin, corresponding member of the USSR Academy of Sciences; I. Polyakov, Department of Darwinism, University of Kharkov; Y. Polyansky, prorector of the University of Leningrad; and A. R. Zhebrak, geneticist, Timiryazev Agricultural Academy.

In the next eight sessions, long speeches by adherents of Lysenko along the general theme of the conference only thinly cloak the main purpose of the assembly, namely, a complete purge of all so-called Mendelist-Morganists from universities, scientific institutes, and agricultural stations of the USSR. Of twenty-four speeches by members of the Lenin Academy of Agricultural Sciences, twenty were pro-Lysenko and were either denunciations of colleagues or preparations for such attacks. Four members of the Lenin Academy were denounced as "Mendelist-Morganists," and amid taunts and with heckling, in part by Lysenko himself, sought to defend themselves as not being anti-Darwin or anti-Michurin. The agricultural specialists, journalists, administrative officials, and others who took part in this conference followed the precedent of Lysenko and indulged in denunciation of their fellows. They added to the list of those on whom Lysenko had already put the finger, J. A. Rapoport, cytologist, Institute of Cytology, Histology, and Embryology, USSR Academy of Sciences; S. I. Alikhanian, geneticist, University of Moscow; and Academician V. S. Nemchinov, statistician and director, the Timiryazev Agricultural Academy. Of the thirty-two speeches by agricultural specialists and others, not members of the Lenin Academy, twenty-eight were pro-Lysenko and four were futile attempts at defense or of explanation by those attacked.

It is difficult to catalogue as to specialty those who were brought together to consider the fitness or unfitness of colleagues and to determine the biological tenets proper for the USSR. Those under attack are well-known investigators who have made important contributions to science in genetics, Darwinian theory, statistics, or cytology. The pro-Lysenkoites, for the

most part, seem characterized by a passion for anonymity. Search of the *Bibliography of Agriculture* for the past ten years shows them either without citations or only as authors of popular articles on agronomy, soil science, general agriculture, and the like; some appear as signators of administrative directives; biochemists who have contributed articles on antibodies, hormones, and blood chemistry are exceptions.

From the publications available and the context of speeches, it would appear that the pro-Lysenko academicians belong in the following fields of specialization: agronomy, 4; biology, 4; plant breeding, 4; animal husbandry, 2; biochemistry, 2; and 1 each in horticulture, soils, agricultural engineering, and genetics. The pro-Lysenkoites who were not Academy members fall into the following categories: agricultural station directors (field of specialization not clear), 8; plant breeders, or Michurin-type geneticists, 7; agricultural administrators, 4; animal breeders, 2; journalists, 2; biochemists, 2; and 1 each, biologist, philosophy professor, and educator. This array of itself indicates the degree of competence of many of the individuals to debate the subject matter of genetics. Any group approval or dissent is obviously without real significance.

In general, the speeches followed a common pattern. Michurin was praised for directing biological thought into proper channels, and Lysenko was glorified for rescuing Michurinism from neglect. Much of the time commonly was devoted to extravagant praise of Lysenko's contributions to Russian agriculture. Many speakers had to rely upon quotations from Lysenko's old addresses, the meager data and specious claims from these sources being quoted and extolled. Frequently the speaker would parade his own work or that of his station and then seek to relate it to the Michurin-Lysenko doctrines. A few reported experiments of the Michurin or Lysenko type that appeared to substantiate the doctrines or were about to do so. None of these was particularly impressive. As the speeches droned on (pages 57–603), each sought to outdo his predecessor in fulsome flattery of Lysenko. No deprecatory statement or gesture on Lysenko's part is anywhere noted in the text, but at times sharp temper was displayed at faint praise or criticism.

The book reinforces the evidence that as a scientist Lysenko is a pygmy. No Haldanish gloss can cover the internal evidences in this volume of the repeated fiascoes that have attended Lysenko's projects. Always the opportunist, he has Potemkinized failures by promises of future successes. As the myth of winter wheat vernalization as a contribution to Soviet agriculture exploded, Lysenko is shown as adroitly suggesting transformation of spring wheat into winter wheat by a process of Michurinistic education to gain winter hardiness and smut resistance! But as he shrinks as a scientist, the book reveals his growth as a consummate politician. Years of scheming and preparation reach successful climax at this meeting. By years of propaganda Lysenko had sold the fettering doctrines of Michurin and had them made party policy. He had in the past ten years planted his henchmen in the agricultural stations and in other positions of power. He had packed the Lenin Academy with his satellites. These were to provide a show of scientific force if such were necessary to accomplish the purge of "Mendelist-Morganists." But decision by the motley group was unnecessary, for Lysenko, the politician, short-circuited the assembly by going directly to the Central Committee of the Communist Party and obtaining the nod from it. After all the speeches were made, Lysenko gave out what R. C. Cook in his article called the "pay-off": "The Central Committee of the Party examined my report and approved it." (*"Stormy applause. Ovation. All rise."*—page 605).

For opponents of Lysenko the jig was up. Then followed a pitiful spectacle as Academician Zhukovsky and Professors Alikhanian and Polyakov abjectly recanted and swore fealty to Lysenko. The sessions closed with the customary letter to Stalin. Lysenko, the politician, lost no time in capitalizing on his victory by drafting a set of resolutions that would force the Academy of Sciences to complete the purge.

If one could overlook the human tragedies involved in this march to power of Lysenko and could disregard the threat to our own freedom that is inherent in state control of man's thinking, then we could dismiss these happenings as medieval and this book as a farrago of nonsense. We could even place it beside *Alice in Wonderland* as high comedy. But this is a deadly serious record, and a menacing one. To the American reader it reveals that in the USSR the situation of biological science is one of utter degradation.

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ANIMALS DOWN UNDER

An Australian Animal Book. (Rev. ed.) Charles Barrett. 374 pp. Illus. $4.50. Oxford University Press. New York.

Charles Barrett, an able "bush naturalist" and writer, has gathered into one volume an account of many of the animals, birds, reptiles, and fishes of his native Australia, a signal work on an amazing fauna—this latter unfortunately thinned in spots by indiscriminate slaughter, so much so that it occurred to me in reading it that "A Study in Extermination" might have been a good subtitle for this book.

Despite the callousness with which the early settlers treated animal life, there still remains in Australia a fauna distinct from that of the rest of the world and reeking with fascinating creatures.

At the present time in Australia, natural history is to the fore. Numerous books have been published,

and this is the third printing of Barrett's. It is recommended to the naturalists of Australia, but it is of interest to naturalists anywhere. He has chosen data written by some of the earliest explorers, has brought it up to date—including the present-day work of David Fleay—and has added many of his own observations. He tells us that the laughing jackass teaches its young to laugh; that the spiny anteater develops a pouch for the purpose of hatching its one egg; that the rifle bird, passing from tree to tree, makes a noise like the shaking of a piece of new stiff silk; that the bowerbirds have been called the most wonderful birds in the world, not especially for their beauty but because one of them builds a most elaborate play hall, a hut of mosses decorated with colored flowers and brilliant beetles. The author has done a fine job in telling something about a vast field.

Some of the colored pictures, from old prints, are delightful, and there are a number of more recent photographs—excellent ones. Although these pictures are good, they are arranged in an exasperating way. Why the American gray squirrel should be in the chapter on marine and fresh-water fishes, and the Australian magpie prefacing the chapter on Australian frogs, is an editorial idea that I cannot comprehend.

It is nevertheless a readable book, full of interesting information.

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SPAIN'S SON OF SCIENCE

Explorer of the Human Brain: The Life of Santiago Ramón y Cajal. Dorothy F. Cannon. xvi + 303 pp. Illus. $4.00. Schuman. New York.

Dr. Dorothy F. Cannon, medical editor for the J. B. Lippincott Co., has performed a real service to science by writing an adequate biography of Santiago Ramón y Cajal, "the greatest scientist Spain has produced and one of the scientific leaders of the world." Though Cajal was a Nobel Prize winner, though many other honors and distinctions were heaped upon him during his lifetime (1852–1934), and though his research upon the nervous system was basic and pioneering, his name is not well known in America except among neurologists and histologists. Dr. Cannon's book, the tenth volume in Schuman's "Life of Science Library," will help correct that.

Like most great thinkers, Cajal's genius radiated in many directions. He was not merely a medical scientist: he was also a dynamic teacher, an ingenious technician, an artist of unusual talent, an investigator of color photography, a creative writer, a philosopher, an educational reformer, and a man of consuming patriotism, whose ambition above everything else was to increase "the sum of Spanish ideas floating in the world." And, withal, he was a man of consummate modesty, of infinite patience and tirelessness. He had an appealing personality. "A bit disconcertingly," says Dr. Cannon, "his weaknesses have proved to be few and are for the most part endearing."

Many of Cajal's discoveries in neural anatomy have today become a fundamental part of neurology. As Dr. Cannon says, they "constitute the basis of our present-day knowledge of the development and structure of the neuron; of the way in which the nervous impulse is transmitted from sense organ to central nervous system and thence to muscle or gland; of the process of degeneration and regeneration of nerve fibers; and of the localization of the various sensory and motor areas of the brain." His Nobel Prize discourse in 1906, *Les structures et connexions des neurones,* made medical history. The new data that he brought to light are of importance to psychologists and psychiatrists: "to a considerable degree it was Cajal's work that made modern neurosurgery and neuropsychiatry possible." Of great significance, too, were the methods he devised for microscopic study, particularly new staining methods. In 1903 he developed the reduced silver-nitrate stain, and in 1913 the gold-sublimate stain, by means of which the neurofibrils, hitherto elusive to study under the microscope, could be traced. These and other ingenious inventions in micrographic techniques opened the way to Cajal's own discoveries and to those of his followers and all future explorers of the nervous system.

Ironically enough, many of Cajal's published papers, year by year reporting upon his researches, did not at first reach a world-wide scientific public, the reason being that they appeared in the scientifically little-read Spanish language, and Cajal lived to see some of his discoveries "rediscovered" by unknowing investigators in other lands. Later most of his works were translated and published in other languages. His *Textura del sistema nerviosa del hombre y de los vertebrados,* also issued in French, is a classic and is, says Dr. Cannon, still the "most complete and accurate description ever made of the more delicate nervous structures." His *Obras literarias completas* were issued in Madrid in 1947.

Into Cajal's story there had to be woven a great deal concerning Spain's civil and political affairs, for his life saw many periods of Spanish turbulence, revolution, and war, including the disgraceful Spanish-American conflict. Cajal lived in no ivory tower, and his long life was closely identified with his country's destiny; and Spanish history from the time of the Cuban uprising in the 1870s (in which he served as medical aide) until the Spanish Civil War of the 1930s is a germane part of his biography.

The whole story of this remarkable doctor is told sympathetically and faithfully by one who knows how to condense material (often technical in nature) and make it interesting for the general reader. The book is prefaced by a memoir of Dr. Cajal by Sir Charles Scott Sherrington, the eminent British physiologist. Appropriately, the volume is published in the fiftieth

anniversary year of Cajal's only visit to the United States, in 1899, when he was one of five distinguished Europeans invited to participate in the Decennial Celebration of Clark University at Worcester.

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REPUBLIC ON THE EQUATOR

Ecuador and the Galápagos Islands. Victor Wolfgang von Hagen. ix + 290 pp. Illus. $3.75. University of Oklahoma Press. Norman.

"ECUADOR," says Victor von Hagen in the Introduction to his latest book, "is a geographical paradox. Here desert, jungle and snow-covered volcanoes follow each other in immediate succession." He then records his impressions of this "land of troubled topography" in a flavorful and interesting volume which is a blend of historical sketches and the quick-drawn impressions of the seasoned traveler.

When Pizarro led his men south from Panama in 1531, he marched through the land now called Ecuador to the center of Inca power in Peru. Then from Lima he sent his captains north to found Quito, the capital on the equator, in 1534. The city grew to command much of the Andes: out of the conquistadors' hunt for gold came other unexpected riches. They sought emeralds and found balsa wood—they looked for the spicy cinnamon bark and discovered the Amazon. Ecuador gave the world the first potato, rubber, quinine, and the Panama hat!

The author weaves the narrative of the development of these resources and crafts against a background of the constantly contrasting Ecuadorean terrain. It is plain the land fascinates him. He is torn between a desire to see a more modern, rational use made of its riches and an unexpressed wish that it be preserved as one vast national park. The naturalist's love for the unspoiled comes clear in his chapter on *el infierno verde*—the "verdured hell" of the Amazonian headwaters. The next chapter is easily the best in the book—a compact and sensitive analysis of the head-hunters' society—the Jivaro Indians. Another chapter explores the caste structure of Ecuadorean society—in fact, one of the underlying themes of the book is the essential neurosis of Andean dwellers—the duality of European conqueror mingled with Indian, which finds its expression in the "hyperbole and melancholy" of the typical Ecuadorean.

The section on the Galápagos stands apart from the main body of the book—like the islands to which it is devoted. The Ecuador of contrasts and color is barely sensed out here 600 miles in the Pacific. The scene is obviously a favorite one of the author's—abounding in remote enchantment and an almost giddy sense of the primeval world. The islands teem with tortoises and tall tales; with pirates, iguanas, castaways, and penguins. Through the volcanic haze are glimpsed the comings and goings of adventurers and scientists, and the reason why the rocky islands gave Darwin the first clues to his world-shaking conclusions is made crystal clear.

The book is well documented, with notes, interesting photographs by the author, a very full bibliography, and index. Mr. von Hagen calls his book an "informal history." He has adapted and refined much material from his earlier volumes, *Off With Their Heads* and *Educador the Unknown*, but this can hardly be called a reference work. Still it should be recommended as an appealing and useful introduction to Ecuador.

One minor personal note. The author makes a dispirited reference to the "much-publicized Pan-American Highway" on page 68. It is this reviewer's opinion that it is precisely lack of publicity that has delayed the completion of this project, which is of top priority for the social and economic growth of the Americas.

BEN GRAUER

National Broadcasting Company
New York City

NATIVE FLORA

American Wild Flowers. Harold N. Moldenke. xv + 453 pp. Illus. $6.95. Van Nostrand. New York.

THIS is the first popular book to describe wild flowers across the country. Fifty chapters describe about 2,000 species by families or related groups, but they are not arranged in systematic sequence. The descriptions are excellent and include distribution, habitat, and economic notes. Thirty-two color plates show eighty-eight very beautiful habitat views of wild flowers, and thirty-two black-and-white plates with excellent detail show sixty-nine species of wild flowers. An illustrated glossary of five pages explains the comparatively few technical terms used in the descriptions. A selected bibliography of sixty-five books covers the principal floras of the country, followed by a fifty-one-page index to the Latin and common names used. The spelling of the common names largely follows those of the 1942 edition of Standardized Plant Names. When the names give a false idea of the relationship of the flower, as, for example, Douglasfir, which is not a fir, and trailing-arbutus, which is not an arbutus, they are written either as a solid or a hyphenated word. Unfortunately, it was not possible for the author to include a key for the identification of the flowers without much increasing the size and cost of the book, so it will remain largely a valuable reference book for the amateur, rather than one for flower identification.

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SOCIETY AND THE SCIENTIST

Controlling Factors in Economic Development. Harold G. Moulton. xii + 397 pp. $4.00. Brookings Institution. Washington.

THE frame of reference within which Dr. Moulton presents his analysis—in effect a summary of the economic studies of the Brookings Institution over the past fifteen years—is the following: There is a sharp dichotomy between "the creative and driving force inherent in the competitive system" and "the stultifying effects of the destruction of individual freedom and initiative that characterize government-controlled and dominated societies. Free enterprise, despite its imperfections, weighs well in the balance."

Interestingly enough, Moulton's optimism—based on capitalism's past performances and future expectation—represents a minority opinion among professional economists. The classical economists, from Ricardo through Cairnes, impressed by the law of diminishing returns, saw no progress open to economic society. In fact, Mill, writing in 1848 and refusing to change his mind in subsequent editions of his *Principles,* expected humankind to sink into a stationary state, with the possibilities of improvement in welfare unlikely. Marx was cut from the same cloth; but, for him, revolution and communism would check the inexorable operations of the law of diminishing returns and the iron law of wages.

The fifty years following 1848 were ones of extraordinary advance: in technology, capital formation, productivity, and real wages. The deductive analyses of the academic economists again and again were proved false by engineers and business enterprisers. Despite the triumphs thus achieved, in the earlier period and in the years since 1921, the economists by and large have continued pessimistic. There have been a few exceptions; and Moulton is to be included in this honorable company.

Since 1934, Moulton and his colleagues have been pursuing their course, studying the productive and consumptive processes of the nation, as well as income distribution and capital formation. The new pessimism of Keynes has shaken their faith little. One may note the great contributions to economic analysis made by the Keynesians, notably in the area of fiscal policy; nevertheless, the palm belongs to Moulton.

The march along the path of economic progress is an unending one; technology can solve the problems of dearth; the consumptive process increases and with it go greater efficiencies, more productivity, and higher real wages; the demand for more rather than less capital is a characteristic of our society. Underdeveloped regions can absorb savings for a long time to come. Recurrent depression is a problem, and compensatory financing can get out of hand: but as long as the world remains the poverty-stricken one it is, capital formation must go on. Management of the economic processes is most effective when directed by private enterprise.

Thus Dr. Moulton in this summary volume. This reviewer concurs in these judgments. More of this type of inductive analysis will take the curse off the "dismal science": and for this the earlier classical economists (Ricardo, Mill, Marx) and the present-day classicists (the Keynesians) are responsible.

LOUIS M. HACKER

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Modern Science and its Philosophy. Philipp Frank. 324 pp. $4.50. Harvard University Press. Cambridge, Mass.

IN THIS selection of sixteen of his essays over a period of forty years (1907–1947), Professor Frank's main aim is to indicate the source of, and the cure for, the warfare and the traditional gaps between philosophy and science. In a remarkably consistent manner his writings take the reader through the maze of the differences between science and philosophy existing in three great eras of thought: Aristotelian-Thomistic, Galilean-Newtonian, and, more recently, Machian-Einsteinian. The major causes for the rifts between the two kinds of truths, the metaphysical (philosophic) and the scientific, may be found in the practical needs of society for stability and conservatism on the one hand, and the unquenchable thirst of the enlightened mind for a search beyond the accepted common sense of the times on the other. But the gaps are man-made and can therefore be smoothed out by man. The means: an application to all phenomena of the heretofore fruitful methodology of the exact sciences, namely, logical empiricism. The kernels of this cure were already envisaged by Plato, later by Hume and Comte, and more recently by Mach, Poincaré, Einstein, P. W. Bridgman, and the members of the "Vienna Circle," of which Carnap, Wittgenstein, and Frank, among others, are distinguished members. The unification of the sciences among themselves and between them and metaphysics can be accomplished by the attitude and the methodology suggested by logical empiricism. Truth for this school is the invention of propositions which can be verified by the senses and is not in the world for all time waiting merely to be discovered. Truth is the matching of a logically coherent system of symbols with large classes of phenomena empirically verifiable by intersubjective agreement. In so far as philosophy or science develops concepts which cannot meet these requirements, i.e., the "unique correspondence" of the symbolic structure of a conceptual schema with a body of verifiable data, these concepts are meaningless, lead to misunderstandings, and even to

suppression by force of one group of people over another. In so far as science and philosophy accept the attitude and methodology of logical empiricism, Frank foresees great benefits accruing to man in every phase of his society. When the social order becomes bogged down with an absolute acceptance and rigid enforcement of absolute "truths," both science and philosophy suffer in the further acquisition of new truths, and, indeed, man himself is the loser. When, however, a continuously vigilant attitude on the part of scientists, philosophers, and laymen alike to the possibility that our basic assumptions concerning ourselves and the universe may be wrong, outmoded, and may be replaced by newer, more fruitful assumptions and hypotheses, then will the gaps between philosophy and science vanish and then will it be possible, because testable, for all men to speak a language that is mutually understandable. And, through understanding—peace and progress.

Frank's aims are admirable; his exposition fine; his breadth and depth enormous; but there is one area which is crucial, and this he neglects or takes for granted, namely, the nature and processes of the human mind. In seeking a unification of the sciences through a dementalization of all concepts and "a complete disintegration of traditional philosophy," he seems to imply that the same approach which is used fruitfully in the physical sciences can yield *meaningful* data in the mental and moral sciences. This is an implication which others before Frank—and even contemporaneously—have endeavored to justify by logico-empirical theories and experiments in psychology and the social sciences but, for the most part, have achieved cold, meaningless results. If the "mechanists" and the "robotists" in psychology and sociology have failed, it may be not because they have not been scientific enough, nor because they have not been intelligent enough, but rather because the nature of the phenomena is perhaps of a different order and demands, therefore, a different approach. A dementalized psychology is not psychology at all; it may be good physiology or good physics, but as such leads us no further into an understanding of ourselves, qua human beings, than a mentalized physics or astronomy gives us an understanding of what happens in the physics lab or in the heavens. Until such time that the mentalistic approaches to the study of psychology and the social sciences generally can definitely be shown to have exhausted their usefulness, it might be hurtful to the further progress in these fields to proclaim confidently that the methods of the physical sciences must inevitably replace them. But until such time that meaningful results are no longer obtained from either approach, i.e., the mentalistic-psychologic and the behavioristic-robotistic, an attitude of mutual tolerance, even mutual aid, in the respective camps can be the only attitude that will benefit the progress of all science and its philosophy.

This is an altogether sound book and is to be warmly recommended to all those in whatever fields who seek to further knowledge by whatever method. Whether or not one agrees with its major premises, one can gain a great deal of stimulation and profit from it. None who reads it can remain unmoved.

PERCY BLACK

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Live with Lightning. Mitchell Wilson. 404 pp. $3.00. Little, Brown. Boston.

IT IS amazing that a book of interest to science should be, as well, an absorbing novel. It is due to the equally unusual fact that the author combines in himself two abilities or techniques. His work in "physics has included research in cosmic rays and high frequency phenomena . . . under such Nobel Laureates as Fermi and Rabi." This is his first novel; his short stories have appeared in our better magazines. Yet the apparently disparate talents are actually of the same nature.

As this novel indicates clearly, the very setting up of problems in physics requires imagination and creative ability of a high order. An empty laboratory at Columbia University becomes vibrant with a great machine capable of one million volts in the neutron bombardment experiment. Erik Gorin goes from that work into machine tool industry, not into production or engineering, but into the theoretical physics necessarily basic to them both. One of his problems is "the mathematical relation between the angles of a cutting tool and the breaking stress of a metal." All his previous work, his dissatisfaction with collegiate pettiness and borderline ethics in industry, lead him during the war to New Mexico and atomic energy research. The reader follows step-by-step experimentation and emerges with real knowledge of matters formerly nebulous; that is the book's genuine contribution.

Meanwhile the story of the novel concerns Erik Gorin's home life and the place of a scientist in society. Is it possible for a man wedded to his science to be a normal member of a community, to lead the life of the average husband and father? In answering this question, the author has created Savina, who is a grand girl and just right for her job as Erik's wife. There are other real characters in the book: physicists, professors, and tycoons. The result is a rounded whole—science made interesting in a spectacular novel.

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CORRESPONDENCE

SHORE PROCESSES

In the first two paragraphs on page 235 of Mr. Caldwell's interesting article "Beach Erosion," he briefly discusses the use of groins and points out some of the difficulties in trying to control shore erosion. Mr. Caldwell mentions only impermeable groins. I would like to call attention to another type, the permeable groin, which I have seen in use in many places on the Great Lakes and especially along the west shore of Lake Michigan.

In my studies of shore processes, I have had occasion to observe both types rather closely and carefully. As Mr. Caldwell infers but does not discuss, evidently for lack of space, the difficulty of the solid groin is that in acting as a solid wing dam it attempts to completely stop the flow of the shore current that is carrying the sediment in suspension. But, from the nature of the case, all the solid groin can really do is to deflect the current away from the shore. When this happens, of course, an area of still water, or sometimes a gentle reverse current, is present on the upstream side in the angle between the groin and the shore, and here deposition of sediment usually occurs. Unfortunately, unless a series of solid groins is so well designed as to fit the shore conditions within very close limits, this sudden checking of current flow sets up local currents and eddies having greater velocities than the original shore current. Where this occurs, erosion is bound to take place. Such currents are apt to be present on the up-current side out near the ends of the groins, and again, in particularly unfortunate cases, a strong reverse eddy develops on the down-current side near the shore. Thus is developed that "sawtooth" effect so often seen in a series of solid groins.

The permeable groin which, instead of acting as a dam, allows a part of the water to pass through it, avoids most of the above difficulties and, at the same time, is equally effective in causing accretion along the shore and preventing erosion. The principles involved are the same as with the solid groin. But, instead of attempting to stop completely the flow of the shore current, the permeable groin seeks only to reduce its velocity and thus cause a partial deposition of the sediment being carried in the shore current. It is evident that complete deposition is not necessary, for, if the effect is such that deposition exceeds erosion, accretion occurs and the purpose of the structure is fulfilled. Because some of the sediment is carried through the permeable groin, deposition takes place on both its up-current and down-current sides. Thus the objectionable sawtooth effect does not develop and there is no "robbing" of the shore, as so often takes place on the down-current side of solid groins.

Of course, neither type of groin can cause accretion unless a shore current is present that carries sediment. On the other hand, on a shore along which no sediment is being transported, the permeable groin seems more protective and less likely to cause damage, since it does not result in dangerous local eddies and currents.

I believe the permeable groin has not been used much along the ocean. However, in view of its apparent advantages and its successful use on the Great Lakes, it would seem that a greater use of it along ocean shores might be desirable.

OREN F. EVANS

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THE ANGLEWORM UNMASKED

Dr. James Thorp, writing in the March issue of THE SCIENTIFIC MONTHLY on "Effects of Certain Animals that Live in Soils," gives all the evidence necessary to debunk the angleworm. To see the full story of the angleworm in its relation to agriculture, let us analyze his remarks.

Dr. Thorp says: ". . . where vegetation is of a type that is appetizing to them, earthworms are very active in converting raw vegetable matter to humus and in mixing the humus with the mineral portion of the soil."

This remark must be modified in two points. First, the raw vegetable matter contained synthesized energy. The worms ate the vegetation and utilized a predominant portion of the synthesized energy in their own body functions, thus preventing its ever coming in contact with roots. The small remainder of unused energy, which is unquestionably good plant food, is deposited in their castings. Second, these worm castings are placed on *top* of the ground where the valuable fertilizer which they contain is washed away and deposited on lowlands already covered with a greater accumulation of humus than is needed.

Thorp presents an illustration of soil that had been covered with fallen leaves, which worms had devoured, leaving small heaps of bare leaf stems (petioles). As a very successful grower of avocados, let me assure the reader that if this had happened in an avocado grove the results would have been disastrous. There are other trees that are *surface feeders* too. The successful avocado grower prizes an accumulation of mulch and would look with much disfavor upon any agency that would strip his soil of its naturally decaying tree food. He would equally dread having the surface of the ground uncovered to the drying effects of sun and wind when his greatest secret of success lies in keeping the *surface* of the soil *moist* and covered with decaying vegetation.

"It is not necessary to assume that the worms have added any new material to the soil . . . but . . . they have facilitated the conversion of raw organic matter to humus . . . ," says Thorp. Why hide the fact that the worms have actually removed the greater part of the nutritive material from the vegetation that they ate? Note that the farmer is in no special hurry to have this year's fallen leaves converted into humus at the expense of the greater part of it! He is satisfied to have the lowest stratum of ten years' supply decay into plant food, remaining on the ground instead of being washed away—remaining there under a cover of dead leaves which also conserves moisture.

The author also admits that worms do not relish pine needles, yet many readers have seen pine or giant redwoods that look fairly prosperous without recourse to angleworms. He says that "Even in desert regions they soon become abundant when moisture conditions and food supply are improved. . . ." He might have added that rats will congregate around unprotected grain.

The ancients said that the earth was flat. Darwin said that earthworms are good. Fortunately for Southern California, earthworms do not eat avocado leaves, at least to any appreciable extent.

CHAPMAN GRANT

San Diego, California

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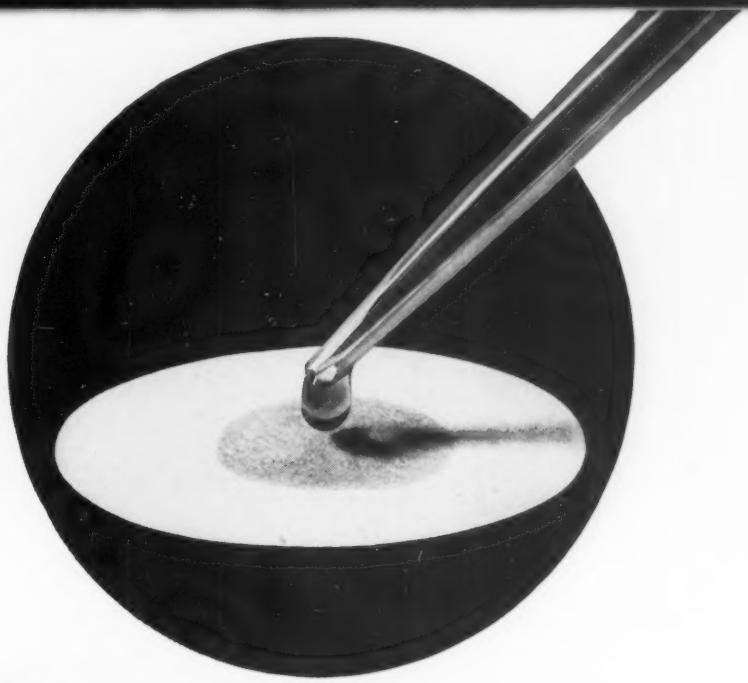

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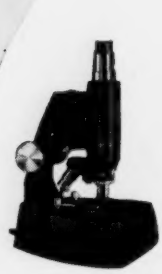

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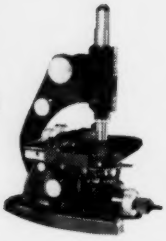

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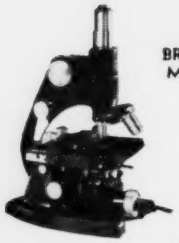

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